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(57) Abstract

The invention provides methods of detecting a nucleic acid. The methods comprise contacting the nucleic acid with one or more types of particles having oligonucleotides attached thereto. In one embodiment of the method, the oligonucleotides are attached to nanoparticles and have sequences complementary to portions of the sequence of the nucleic acid. A detectable change (preferably a color change) is brought about as a result of the hybridization of the oligonucleotides on the nanoparticles to the nucleic acid. The invention also provides compositions and kits comprising particles. The invention further provides nanomaterials and nanostructures comprising nanoparticles and methods of nanofabrication utilizing the nanoparticles. Finally, the invention provides a method of separating a selected nucleic acid from other nucleic acids.

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NANOPARTICLES HAVING OLIGONUCLEOTIDES ATTACHED THERETO AND USES THEREFOR

This invention was made with government support under National Institutes Of Health grant GM10265. The government has certain rights in the invention.

Benefit of provisional application number 60/031,809, filed July 29, 1996, is hereby claimed.

FIELD OF THE INVENTION

The invention relates to methods of detecting nucleic acids, whether natural or synthetic, and whether modified or unmodified. This invention also relates to methods of nanofabrication. Finally, the invention relates to methods of separating a selected nucleic acid from other nucleic acids.

BACKGROUND OF THE INVENTION

The development of methods for detecting and sequencing nucleic acids is critical to the diagnosis of genetic, bacterial, and viral diseases. *See* Mansfield, E.S. et al. *Molecular and Cellular Probes*, **9**, 145-156 (1995). At present, there are a variety of methods used for detecting specific nucleic acid sequences. *Id.* However, these methods are complicated, time-consuming and/or require the use of specialized and expensive equipment. A simple, fast method of detecting nucleic acids which does not require the use of such equipment would clearly be desirable.

A variety of methods have been developed for assembling metal and semiconductor colloids into nanomaterials. These methods have focused on the use of covalent linker molecules that possess functionalities at opposing ends with chemical affinities for the colloids of interest. One of the most successful approaches to

date, Brust et al., *Adv. Mater.*, **7**, 795-797 (1995), involves the use of gold colloids and well-established thiol adsorption chemistry, Bain & Whitesides, *Angew. Chem. Int. Ed. Engl.*, **28**, 506-512 (1989) and Dubois & Nuzzo, *Annu. Rev. Phys. Chem.*, **43**, 437-464 (1992). In this approach, linear alkanedithiols are used as the particle linker molecules. The thiol groups at each end of the linker molecule covalently attach themselves to the colloidal particles to form aggregate structures. The drawbacks of this method are that the process is difficult to control and the assemblies are formed irreversibly. Methods for systematically controlling the assembly process are needed if the materials properties of these structures are to be exploited fully.

The potential utility of DNA for the preparation of biomaterials and in nanofabrication methods has been recognized. In this work, researchers have focused on using the sequence-specific molecular recognition properties of oligonucleotides to design impressive structures with well-defined geometric shapes and sizes. Shekhtman et al., *New J. Chem.*, **17**, 757-763 (1993); Shaw & Wang, *Science*, **260**, 533-536 (1993); Chen et al., *J. Am Chem. Soc.*, **111**, 6402-6407 (1989); Chen & Seeman, *Nature*, **350**, 631-633 (1991); Smith and Feigon, *Nature*, **356**, 164-168 (1992); Wang et al., *Biochem.*, **32**, 1899-1904 (1993); Chen et al., *Biochem.*, **33**, 13540-13546 (1994); Marsh et al., *Nucleic Acids Res.*, **23**, 696-700 (1995); Mirkin, *Annu. Review Biophys. Biomol. Struct.*, **23**, 541-576 (1994); Wells, *J. Biol. Chem.*, **263**, 1095-1098 (1988); Wang et al., *Biochem.*, **30**, 5667-5674 (1991). However, the theory of producing DNA structures is well ahead of experimental confirmation. Seeman et al., *New J. Chem.*, **17**, 739-755 (1993).

SUMMARY OF THE INVENTION

The invention provides methods of detecting nucleic acids. In one embodiment, the method comprises contacting a nucleic acid with one or more types of nanoparticles having oligonucleotides attached thereto (nanoparticle-oligonucleotide conjugates). The nucleic acid has at least two portions, and the oligonucleotides on each of the types of nanoparticles have a sequence complementary to the sequence of one of the portions of the nucleic acid. The contacting takes place under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the nucleic acid. The hybridization of the oligonucleotides on the nanoparticles with the nucleic acid results in a detectable change.

In another embodiment, the method comprises contacting a nucleic acid with at least two types of nanoparticles having oligonucleotides attached thereto. The oligonucleotides on the first type of nanoparticles have a sequence complementary to a first portion of the sequence of the nucleic acid. The oligonucleotides on the second type of nanoparticles have a sequence complementary to a second portion of the sequence of the nucleic acid. The contacting takes place under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the nucleic acid, and a detectable change brought about by this hybridization is observed.

In a further embodiment, the method comprises providing a substrate having a first type of nanoparticles attached thereto. The first type of nanoparticles has oligonucleotides attached thereto, and the oligonucleotides have a sequence complementary to a first portion of the sequence of a nucleic acid. The substrate is contacted with the nucleic acid under

conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the nucleic acid. Then, a second type of nanoparticles having oligonucleotides attached thereto is provided. The oligonucleotides have a sequence complementary to one or more other portions of the sequence of the nucleic acid, and the nucleic acid bound to the substrate is contacted with the second type of nanoparticle-oligonucleotide conjugates under conditions effective to allow hybridization of the oligonucleotides on the second type of nanoparticles with the nucleic acid. A detectable change may be observable at this point. The method may further comprise providing a binding oligonucleotide having a selected sequence having at least two portions, the first portion being complementary to at least a portion of the sequence of the oligonucleotides on the second type of nanoparticles. The binding oligonucleotide is contacted with the second type of nanoparticle-oligonucleotide conjugates bound to the substrate under conditions effective to allow hybridization of the binding oligonucleotide to the oligonucleotides on the nanoparticles. Then, a third type of nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to the sequence of a second portion of the binding oligonucleotide, is contacted with the binding oligonucleotide bound to the substrate under conditions effective to allow hybridization of the binding oligonucleotide to the oligonucleotides on the nanoparticles. Finally, the detectable change produced by these hybridizations is observed.

In yet another embodiment, the method comprises contacting a nucleic acid with a substrate having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to a first portion of the

sequence of the nucleic acid. The contacting takes place under conditions effective to allow hybridization of the oligonucleotides on the substrate with the nucleic acid. Then, the nucleic acid bound to the substrate is contacted with a first type of nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to a second portion of the sequence of the nucleic acid. The contacting takes place under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the nucleic acid. Next, the first type of nanoparticle-oligonucleotide conjugates bound to the substrate is contacted with a second type of nanoparticles having oligonucleotides attached thereto, the oligonucleotides on the second type of nanoparticles having a sequence complementary to at least a portion of the sequence of the oligonucleotides on the first type of nanoparticles, the contacting taking place under conditions effective to allow hybridization of the oligonucleotides on the first and second types of nanoparticles. Finally, a detectable change produced by these hybridizations is observed.

In another embodiment, the method comprises contacting a nucleic acid with a substrate having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to a first portion of the sequence of the nucleic acid. The contacting takes place under conditions effective to allow hybridization of the oligonucleotides on the substrate with the nucleic acid. Then, the nucleic acid bound to the substrate is contacted with liposomes having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to a portion of the sequence of the nucleic acid. This contacting takes place under conditions effective to allow hybridization of the oligonucleotides on the liposomes with the nucleic acid. Next, the

liposome-oligonucleotide conjugates bound to the substrate are contacted with a first type of nanoparticles having at least a first type oligonucleotides attached thereto. The first type of oligonucleotides have a hydrophobic group attached to the end not attached to the nanoparticles, and the contacting takes place under conditions effective to allow attachment of the oligonucleotides on the nanoparticles to the liposomes as a result of hydrophobic interactions. A detectable change may be observable at this point. The method may further comprise contacting the first type of nanoparticle-oligonucleotide conjugates bound to the liposomes with a second type of nanoparticles having oligonucleotides attached thereto. The first type of nanoparticles have a second type of oligonucleotides attached thereto which have a sequence complementary to at least a portion of the sequence of the oligonucleotides on the second type of nanoparticles, and the oligonucleotides on the second type of nanoparticles having a sequence complementary to at least a portion of the sequence of the second type of oligonucleotides on the first type of nanoparticles. The contacting takes place under conditions effective to allow hybridization of the oligonucleotides on the first and second types of nanoparticles. Then, a detectable change is observed.

In yet another embodiment, the method comprises providing nanoparticles having oligonucleotides attached thereto and providing one or more types of binding oligonucleotides. Each of the binding oligonucleotides has two portions. The sequence of one portion is complementary to the sequence of one of the portions of the nucleic acid, and the sequence of the other portion is complementary to the sequence of the oligonucleotides on the nanoparticles. The nanoparticle-oligonucleotide conjugates and the binding oligonucleotides are contacted

under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the binding oligonucleotides. The nucleic acid and the binding oligonucleotides are contacted under conditions effective to allow hybridization of the binding oligonucleotides with the nucleic acid. Then, a detectable change is observed. The nanoparticle-oligonucleotide conjugates may be contacted with the binding oligonucleotides prior to being contacted with the nucleic acid, or all three may be contacted simultaneously.

In another embodiment, the method comprises contacting a nucleic acid with at least two types of particles having oligonucleotides attached thereto. The oligonucleotides on the first type of particles have a sequence complementary to a first portion of the sequence of the nucleic acid and have energy donor molecules on the ends not attached to the particles. The oligonucleotides on the second type of particles have a sequence complementary to a second portion of the sequence of the nucleic acid and have energy acceptor molecules on the ends not attached to the particles. The contacting takes place under conditions effective to allow hybridization of the oligonucleotides on the particles with the nucleic acid, and a detectable change brought about by this hybridization is observed. The energy donor and acceptor molecules may be fluorescent molecules.

The invention further provides kits for detecting nucleic acids. In one embodiment, the kit comprises at least one container, the container holding at least two types of nanoparticles having oligonucleotides attached thereto. The oligonucleotides on the first type of nanoparticles have a sequence complementary to the sequence of a first portion of a nucleic acid. The oligonucleotides on the second type of nanoparticles have

a sequence complementary to the sequence of a second portion of the nucleic acid.

Alternatively, the kit may comprise at least two containers. The first container holds nanoparticles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid. The second container holds nanoparticles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a second portion of the nucleic acid.

In a further embodiment, the kit comprises at least one container. The container holds metallic or semiconductor nanoparticles having oligonucleotides attached thereto. The oligonucleotides have a sequence complementary to portion of a nucleic acid and have fluorescent moelcules attached to the ends of the oligonucleotides not attached to the nanoparticles.

In yet another embodiment, the kit comprises a substrate, the substrate having attached thereto nanoparticles, the nanoparticles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid. The kit also includes a first container holding nanoparticles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a second portion of the nucleic acid. The kit further includes a second container holding a binding oligonucleotide having a selected sequence having at least two portions, the first portion being complementary to at least a portion of the sequence of the oligonucleotides on the nanoparticles in the first container. The kit also includes a third container holding nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to the sequence of a second portion of the binding oligonucleotide.

In another embodiment, the kit comprises a substrate having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid, a first container holding nanoparticles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a second portion of the nucleic acid, and a second container holding nanoparticles having oligonucleotides attached thereto which have a sequence complementary to at least a portion of the oligonucleotides attached to the nanoparticles in the first container.

In yet another embodiment, the kit comprises a substrate, a first container holding nanoparticles, a second container holding a first type of oligonucleotides having a sequence complementary to the sequence of a first portion of a nucleic acid, a third container holding a second type of oligonucleotides having a sequence complementary to the sequence of a second portion of the nucleic acid, and a fourth container holding a third type of oligonucleotides having a sequence complementary to at least a portion of the sequence of the second type of oligonucleotides.

In a further embodiment, the kit comprises a substrate having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid. The kit also includes a first container holding liposomes having oligonucleotides attached thereto which have a sequence complementary to the sequence of a second portion of the nucleic acid and a second container holding nanoparticles having at least a first type of oligonucleotides attached thereto, the first type of oligonucleotides having a hydrophobic group attached to the end not attached to the nanoparticles so that the nanoparticles can be attached to the liposomes by hydrophobic interactions. The kit may further

comprise a third container holding a second type of nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to at least a portion of the sequence of a second type of oligonucleotides attached to the first type of nanoparticles. The second type of oligonucleotides attached to the first type of nanoparticles have a sequence complementary to the sequence of the oligonucleotides on the second type of nanoparticles.

In a further embodiment, the kit comprises a first container holding nanoparticles having oligonucleotides attached thereto. The kit also includes one or more additional containers, each container holding a binding oligonucleotide. Each binding oligonucleotide has a first portion which has a sequence complementary to at least a portion of the sequence of oligonucleotides on the nanoparticles and a second portion which has a sequence complementary to the sequence of a portion of a nucleic acid to be detected. The sequences of the second portions of the binding oligonucleotides may be different as long as each sequence is complementary to a portion of the sequence of the nucleic acid to be detected.

In yet another embodiment, the kit comprises a container holding one type of nanoparticles having oligonucleotides attached thereto and one or more types of binding oligonucleotides. Each of the types of binding oligonucleotides has a sequence comprising at least two portions. The first portion is complementary to the sequence of the oligonucleotides on the nanoparticles, whereby the binding oligonucleotides are hybridized to the oligonucleotides on the nanoparticles in the container(s). The second portion is complementary to the sequence of a portion of the nucleic acid.

In another alternative embodiment, the kit comprises at least three containers. The first container holds

nanoparticles. The second container holds a first oligonucleotide having a sequence complementary to the sequence of a first portion of a nucleic acid. The third container holds a second oligonucleotide having a sequence complementary to the sequence of a second portion of the nucleic acid. The kit may further comprise a fourth container holding a binding oligonucleotide having a selected sequence having at least two portions, the first portion being complementary to at least a portion of the sequence of the second oligonucleotide, and a fifth container holding an oligonucleotide having a sequence complementary to the sequence of a second portion of the binding oligonucleotide.

In another embodiment, the kit comprises one or two containers, the container(s) holding two types of particles. The first type of particles having oligonucleotides attached thereto that have a sequence complementary to a first portion of the sequence of a nucleic acid and have energy donor molecules attached to the ends not attached to the nanoparticles. The second type of particles having oligonucleotides attached thereto that have a sequence complementary to a second portion of the sequence of a nucleic acid and have energy acceptor molecules attached to the ends not attached to the nanoparticles. The energy donors and acceptors may be fluorescent molecules.

The invention also provides a substrate having nanoparticles attached thereto. The nanoparticles may have oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid.

The invention further provides a method of nanofabrication. The method comprises providing at least one type of linking oligonucleotide having a selected

sequence, the sequence of each type of linking oligonucleotide having at least two portions. The method further comprises providing one or more types of nanoparticles having oligonucleotides attached thereto, the oligonucleotides on each type of nanoparticles having a sequence complementary to a portion of the sequence of a linking oligonucleotide. The linking oligonucleotides and nanoparticles are contacted under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles to the linking oligonucleotides so that a desired nanomaterial or nanostructure is formed.

The invention provides another method of nanofabrication. This method comprises providing at least two types of nanoparticles having oligonucleotides attached thereto. The oligonucleotides on the first type of nanoparticles have a sequence complementary to that of the oligonucleotides on the second type of nanoparticles. The oligonucleotides on the second type of nanoparticles have a sequence complementary to that of the oligonucleotides on the first type of nanoparticle-oligonucleotide conjugates. The first and second types of nanoparticles are contacted under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles to each other so that a desired nanomaterial or nanostructure is formed.

The invention further provides nanomaterials or nanostructures composed of nanoparticles having oligonucleotides attached thereto, the nanoparticles being held together by oligonucleotide connectors.

The invention also provides a composition comprising at least two types of nanoparticles having oligonucleotides attached thereto. The oligonucleotides on the first type of nanoparticles have a sequence complementary to the sequence of a first portion of a nucleic acid or a linking oligonucleotide. The

oligonucleotides on the second type of nanoparticles have a sequence complementary to the sequence of a second portion of the nucleic acid or linking oligonucleotide.

The invention further provides an assembly of containers comprising a first container holding nanoparticles having oligonucleotides attached thereto, and a second container holding nanoparticles having oligonucleotides attached thereto. The oligonucleotides attached to the nanoparticles in the first container have a sequence complementary to that of the oligonucleotides attached to the nanoparticles in the second container. The oligonucleotides attached to the nanoparticles in the second container have a sequence complementary to that of the oligonucleotides attached to the nanoparticles in the first container.

The invention also provides a nanoparticle having a plurality of different oligonucleotides attached to it.

Finally, the invention provides a method of separating a selected nucleic acid having at least two portions from other nucleic acids. The method comprises providing one or more types of nanoparticles having oligonucleotides attached thereto, the oligonucleotides on each of the types of nanoparticles having a sequence complementary to the sequence of one of the portions of the selected nucleic acid. The selected and other nucleic acids are contacted with the nanoparticles under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the selected nucleic acid so that the nanoparticles hybridized to the selected nucleic acid aggregate and precipitate.

As used herein, a "type of oligonucleotides" refers to a plurality of oligonucleotide molecules having the same sequence. A "type of nanoparticles having oligonucleotides attached thereto" refers to a plurality of nanoparticles having the same type(s) of

oligonucleotides attached to them. "Nanoparticles having oligonucleotides attached thereto" are also sometimes referred to as "nanoparticle-oligonucleotide conjugates" or, in the case of the detection methods of the invention, "nanoparticle-oligonucleotide probes," "nanoparticle probes," or just "probes."

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1: Schematic diagram illustrating the formation of nanoparticle aggregates by combining nanoparticles having complementary oligonucleotides attached to them, the nanoparticles being held together in the aggregates as a result of the hybridization of the complementary oligonucleotides. X represents any covalent anchor (such as $-S(CH_2)_3OP(O)(O^-)-$, where S is joined to a gold nanoparticle). For the sake of simplicity in Figure 1 and some subsequent figures, only one oligonucleotide is shown to be attached to each particle but, in fact, each particle has several oligonucleotides attached to it. Also, it is important to note that in Figure 1 and subsequent figures, the relative sizes of the gold nanoparticles and the oligonucleotides are not drawn to scale.

Figure 2: Schematic diagram illustrating a system for detecting nucleic acid using nanoparticles having oligonucleotides attached thereto. The oligonucleotides on the two nanoparticles have sequences complementary to two different portions of the single-stranded DNA shown. As a consequence, they hybridize to the DNA producing detectable changes (forming aggregates and producing a color change).

Figure 3: Schematic diagram of a variation of the system shown in Figure 2. The oligonucleotides on the two nanoparticles have sequences complementary to two different portions of the single-stranded DNA shown which

are separated by a third portion which is not complementary to the oligonucleotides on the nanoparticles. Also shown is an optional filler oligonucleotide which can be used to hybridize with the noncomplementary portion of the single-stranded DNA. When the DNA, nanoparticles and filler oligonucleotides are combined, the nanoparticles aggregate, with the formation of nicked, double-stranded oligonucleotide connectors.

Figure 4: Schematic diagram illustrating reversible aggregation of nanoparticles having oligonucleotides attached thereto as a result of hybridization and de-hybridization with a linking oligonucleotide. The illustrated linking oligonucleotide is a double-stranded DNA having overhanging termini (sticky ends) which are complementary to the oligonucleotides attached to the nanoparticles.

Figure 5: Schematic diagram illustrating the formation of nanoparticle aggregates by combining nanoparticles having oligonucleotides attached thereto with linking oligonucleotides having sequences complementary to the oligonucleotides attached to the nanoparticles.

Figure 6: Cuvettes containing two types of gold colloids, each having a different oligonucleotide attached thereto and a linking double-stranded oligonucleotide with sticky ends complementary to the oligonucleotides attached to the nanoparticles (see Figure 4). Cuvette A - at 80°C, which is above the Tm of the linking DNA; de-hybridized (thermally denatured). The color is dark red. Cuvette B - after cooling to room temperature, which is below the Tm of the linking DNA; hybridization has taken place, and the nanoparticles have aggregated, but the aggregates have not precipitated. The color is purple. Cuvette C - after several hours at

room temperature, the aggregated nanoparticles have settled to the bottom of the cuvette. The solution is clear, and the precipitate is pinkish gray. Heating B or C will result in A.

Figure 7: A graph of absorbance versus wavelength in nm showing changes in absorbance when gold nanoparticles having oligonucleotides attached thereto aggregate due to hybridization with linking oligonucleotides upon lowering of the temperature, as illustrated in Figure 4.

Figures 8A-B: Figure 8A is a graph of change in absorbance versus temperature/time for the system illustrated in Figure 4. At low temperatures, gold nanoparticles having oligonucleotides attached thereto aggregate due to hybridization with linking oligonucleotides (see Figure 4). At high temperature (80°C), the nanoparticles are de-hybridized. Changing the temperature over time shows that this is a reversible process. Figure 8B is a graph of change in absorbance versus temperature/time performed in the same manner using an aqueous solution of unmodified gold nanoparticles. The reversible changes seen in Figure 8A are not observed.

Figures 9A-B: Transmission Electron Microscope (TEM) images. Figure 9A is a TEM image of aggregated gold nanoparticles held together by hybridization of the oligonucleotides on the gold nanoparticles with linking oligonucleotides. Figure 9B is a TEM image of a two-dimensional aggregate showing the ordering of the linked nanoparticles.

Figure 10: Schematic diagram illustrating the formation of thermally-stable triple-stranded oligonucleotide connectors between nanoparticles having the pyrimidine:purine:pyrimidine motif. Such triple-stranded connectors are stiffer than double-stranded

connectors. In Figure 10, one nanoparticle has an oligonucleotide attached to it which is composed of all purines, and the other nanoparticle has an oligonucleotide attached to it which is composed of all pyrimidines. The third oligonucleotide for forming the triple-stranded connector (not attached to a nanoparticle) is composed of pyrimidines.

Figure 11: Schematic diagram illustrating the formation of nanoparticle aggregates by combining nanoparticles having complementary oligonucleotides attached to them, the nanoparticles being held together in the aggregates as a result of the hybridization of the complementary oligonucleotides. In Figure 11, the circles represent the nanoparticles, the formulas are oligonucleotide sequences, s is the thio-alkyl linker, and the squiggles on the circles represent other oligonucleotide molecules of the same sequence as indicated that cover the surface of the nanoparticles. The multiple oligonucleotides on the two types of nanoparticles can hybridize to each other, leading to the formation of an aggregate structure.

Figure 12: Schematic diagrams illustrating systems for detecting nucleic acid using nanoparticles having oligonucleotides attached thereto. Oligonucleotide-nanoparticle conjugates 1 and 2 and single-stranded oligonucleotide targets 3, 4, 5, 6 and 7 are illustrated. In Figure 12, the circles represent the nanoparticles, the formulas are oligonucleotide sequences, and the dotted lines represent connecting links of nucleotide.

Figures 13A-B: Schematic diagrams illustrating systems for detecting DNA (analyte DNA) using nanoparticles and a transparent substrate.

Figures 14A-B: Figure 14A is a graph of absorbance versus wavelength in nm showing changes in absorbance when gold nanoparticles having oligonucleotides attached

thereto (one population of which is in solution and one population of which is attached to a transparent substrate as illustrated in Figure 13B) aggregate due to hybridization with linking oligonucleotides. Figure 14B a graph of change in absorbance for the hybridized system referred to in Figure 14A as the temperature is increased (melted).

Figure 15: Schematic diagrams illustrating systems for detecting nucleic acid using nanoparticles having oligonucleotides attached thereto. Oligonucleotide-nanoparticle conjugates 1 and 2 and single-stranded oligonucleotide targets 3, 4, 5, 6, 7 and 8 are illustrated. In Figure 15, the circles represent the nanoparticles, the formulas are oligonucleotide sequences, and S represents the thio-alkyl linker.

Figure 16: Schematic diagrams illustrating systems for detecting nucleic acid using nanoparticles having oligonucleotides attached thereto. Oligonucleotide-nanoparticle conjugates 1 and 2, single-stranded oligonucleotide targets of different lengths, and filler oligonucleotides of different lengths are illustrated. In Figure 16, the circles represent the nanoparticles, the formulas are oligonucleotide sequences, and S represents the thio-alkyl linker.

Figure 17: Schematic diagrams illustrating nanoparticle-oligonucleotide conjugates and systems for detecting nucleic acid using nanoparticles having oligonucleotides attached thereto. In Figure 17, the circles represent the nanoparticles, the straight lines represent oligonucleotide chains (bases not shown), two closely-spaced parallel lines represent duplex segments, and the small letters indicate specific nucleotide sequences (a is complementary to a', b is complementary to b', etc.).

Figure 18: Schematic diagram illustrating a system for detecting nucleic acid using liposomes (large double circle), nanoparticles (small dark circles) and a transparent substrate. In figure 18, the filled-in squares represent cholesteryl groups, the squiggles represent oligonucleotides, and the ladders represent double-stranded (hybridized) oligonucleotides.

Figures 19A-B: Figure 19A is a graph of absorbance versus wavelength in nm showing changes in absorbance when gold nanoparticle-oligonucleotide conjugates assemble in multiple layers on a transparent substrate as illustrated in Figure 13A. Figure 19B is a graph of change in absorbance for the hybridized system referred to in Figure 19A as the temperature is increased (melted).

Figures 20A-B: Illustrations of schemes using fluorescent-labeled oligonucleotides attached to metallic or semiconductor quenching nanoparticles (Figure 20A) or to non-metallic, non-semiconductor particles (Figure 20B).

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

Nanoparticles useful in the practice of the invention include metal (*e.g.*, gold, silver, copper and platinum), semiconductor (*e.g.*, CdSe and CdS) and magnetic (*e.g.*, ferromagnetite) colloidal materials. Other nanoparticles useful in the practice of the invention include ZnS, ZnO, TiO_2, AgI, AgBr, HgI_2, PbS, PbSe, ZnTe, CdTe, In_2S_3, In_2Se_3, Cd_3P_2, Cd_3As_2, InAs, and GaAs. The size of the nanoparticles is preferably from about 5 nm to about 150 nm (mean diameter), more preferably from about 5 to about 50 nm, most preferably from about 10 to about 30 nm.

Methods of making metal, semiconductor and magnetic nanoparticles are well-known in the art. See, *e.g.*, Schmid, G. (ed.) *Clusters and Colloids* (VCH, Weinheim, 1994); Hayat, M.A. (ed.) *Colloidal Gold: Principles, Methods, and Applications* (Academic Press, San Diego, 1991); Massart, R., *IEEE Taransactions On Magnetics*, **17**, 1247 (1981); Ahmadi, T.S. et al., *Science*, **272**, 1924 (1996); Henglein, A. et al., *J. Phys. Chem.*, **99**, 14129 (1995); Curtis, A.C., et al., *Angew. Chem. Int. Ed. Engl.*, **27**, 1530 (1988).

Methods of making ZnS, ZnO, TiO_2, AgI, AgBr, HgI_2, PbS, PbSe, ZnTe, CdTe, In_2S_3, In_2Se_3, Cd_3P_2, Cd_3As_2, InAs, and GaAs nanoparticles are also known in the art. See, *e.g.*, Weller, *Angew. Chem. Int. Ed. Engl.*, **32**, 41 (1993); Henglein, *Top. Curr. Chem.*, **143**, 113 (1988); Henglein, *Chem. Rev.*, **89**, 1861 (1989); Brus, *Appl. Phys. A.*, **53**, 465 (1991); Bahncmann, in Photochemical Conversion and Storage of Solar Energy (eds. Pelizetti and Schiavello 1991), page 251; Wang and Herron, *J. Phys. Chem.*, **95**, 525 (1991); Olshavsky et al., *J. Am. Chem. Soc.*, **112**, 9438 (1990); Ushida et al., *J. Phys. Chem.*, **95**, 5382 (1992).

Suitable nanoparticles are also commercially available from, *e.g.*, Ted Pella, Inc. (gold), Amersham Corporatrion (gold) and Nanoprobes, Inc. (gold).

Presently preferred for use in detecting nucleic acids are gold nanoparticles. Gold colloidal particles have high extinction coefficients for the bands that give rise to their beautiful colors. These intense colors change with particle size, concentration, interparticle distance, and extent of aggregation and shape (geometry) of the aggregates, making these materials particularly attractive for colorimetric assays. For instance, hybridization of oligonucleotides attached to gold nanoparticles with oligonucleotides and nucleic acids

results in an immediate color change visible to the naked eye (see, *e.g.*, the Examples).

Gold nanoparticles are also presently preferred for use in nanofabrication for the same reasons given above and because of their stability, ease of imaging by electron microscopy, and well-characterized modification with thiol functionalities (see below).

The nanoparticles, the oligonucleotides or both are functionalized in order to attach the oligonucleotides to the nanoparticles. Such methods are known in the art. For instance, oligonucleotides functionalized with alkanethiols at their 3'-termini or 5'-termini readily attach to gold nanoparticles. See Whitesides, *Proceedings of the Robert A. Welch Foundation 39th Conference On Chemical Research Nanophase Chemistry*, Houston, TX, pages 109-121 (1995). See also, Mucic et al. *Chem. Commun.* 555-557 (1996) (describes a method of attaching 3' thiol DNA to flat gold surfaces; this method can be used to attach oligonucleotides to nanoparticles). The alkanethiol method can also be used to attach oligonucleotides to other metal, semiconductor and magnetic colloids and to the other nanoparticles listed above. Other functional groups for attaching oligonucleotides to solid surfaces include phosphorothioate groups (see, *e.g.*, U.S. Patent No. 5,472,881 for the binding of oligonucleotide-phosphorothioates to gold surfaces), substituted alkylsiloxanes (see, *e.g.* Burwell, *Chemical Technology*, **4**, 370-377 (1974) and Matteucci and Caruthers, *J. Am. Chem. Soc.*, **103**, 3185-3191 (1981) for binding of oligonucleotides to silica and glass surfaces, and Grabar et al., *Anal. Chem.*, **67**, 735-743 for binding of aminoalkylsiloxanes and for similar binding of mercaptoaklylsiloxanes). Oligonucleotides terminated with a 5' thionucleoside or a 3' thionucleoside may also

be used for attaching oligonucleotides to solid surfaces. Gold nanoparticles may be attached to oligonucleotides using biotin-labeled oligonucleotides and streptavidin-gold conjugate colloids; the biotin-streptavidin interaction attaches the colloids to the oligonucleotide. Shaiu et al., *Nuc. Acids Res.*, **21**, 99 (1993). The following references describe other methods which may be employed to attached oligonucleotides to nanoparticles: Nuzzo et al., *J. Am. Chem. Soc.*, **109**, 2358 (1987) (disulfides on gold); Allara and Nuzzo, *Langmuir*, **1**, 45 (1985) (carboxylic acids on aluminum); Allara and Tompkins, *J. Colloid Interface Sci.*, **49**, 410-421 (1974) (carboxylic acids on copper); Iler, The Chemistry Of Silica, Chapter 6, (Wiley 1979) (carboxylic acids on silica); Timmons and Zisman, *J. Phys. Chem.*, **69**, 984-990 (1965) (carboxylic acids on platinum); Soriaga and Hubbard, *J. Am. Chem. Soc.*, **104**, 3937 (1982) (aromatic ring compounds on platinum); Hubbard, *Acc. Chem. Res.*, **13**, 177 (1980) (sulfolanes, sulfoxides and other functionalized solvents on platinum); Hickman et al., *J. Am. Chem. Soc.*, **111**, 7271 (1989) (isonitriles on platinum); Maoz and Sagiv, *Langmuir*, **3**, 1045 (1987) (silanes on silica); Maoz and Sagiv, *Langmuir*, **3**, 1034 (1987) (silanes on silica); Wasserman et al., *Langmuir*, **5**, 1074 (1989) (silanes on silica); Eltekova and Eltekov, *Langmuir*, **3**, 951 (1987) (aromatic carboxylic acids, aldehydes, alcohols and methoxy groups on titanium dioxide and silica); Lec et al., *J. Phys. Chem.*, **92**, 2597 (1988) (rigid phosphates on metals).

Each nanoparticle will have a plurality of oligonucleotides attached to it. As a result, each nanoparticle-oligonucleotide conjugate can bind to a plurality of oligonucleotides or nucleic acids having the complementary sequence.

Oligonucleotides of defined sequences are used for a variety of purposes in the practice of the invention. Methods of making oligonucleotides of a predetermined sequence are well-known. See, *e.g.*, Sambrook *et al.*, *Molecular Cloning: A Laboratory Manual* (2nd ed. 1989) and F. Eckstein (ed.) *Oligonucleotides and Analogues*, 1st Ed. (Oxford University Press, New York, 1991). Solid-phase synthesis methods are preferred for both oligoribonucleotides and oligodeoxyribonucleotides (the well-known methods of synthesizing DNA are also useful for synthesizing RNA). Oligoribonucleotides and oligodeoxyribonucleotides can also be prepared enzymatically.

The invention provides methods of detecting nucleic acids. Any type of nucleic acid may be detected, and the methods may be used, *e.g.*, for the diagnosis of disease and in sequencing of nucleic acids. Examples of nucleic acids that can be detected by the methods of the invention include genes (*e.g.*, a gene associated with a particular disease), viral RNA and DNA, bacterial DNA, fungal DNA, cDNA, mRNA, RNA and DNA fragments, oligonucleotides, synthetic oligonucleotides, modified oligonucleotides, single-stranded and double-stranded nucleic acids, natural and synthetic nucleic acids, etc. Thus, examples of the uses of the methods of detecting nucleic acids include: the diagnosis and/or monitoring of viral diseases (*e.g.*, human immunodeficiency virus, hepatitis viruses, herpes viruses, cytomegalovirus, and Epstein-Barr virus), bacterial diseases (*e.g.*, tuberculosis, Lyme disease, *H. pylori*, *Escherichia coli* infections, *Legionella* infections, *Mycoplasma* infections, *Salmonella* infections), sexually transmitted diseases (*e.g.*, gonorrhoea), inherited disorders (*e.g.*, cystic fibrosis, Duchene muscular dystrophy, phenylketonuria,

sickle cell anemia), and cancers (*e.g.*, genes associated with the development of cancer); in forensics; in DNA sequencing; for paternity testing; for cell line authentication; for monitoring gene therapy; and for many other purposes.

The methods of detecting nucleic acids based on observing a color change with the naked eye are cheap, fast, simple, robust (the reagents are stable), do not require specialized or expensive equipment, and do not require any instrumentation. This makes them particularly suitable for use in, *e.g.*, research and analytical laboratories in DNA sequencing, in the field to detect the presence of specific pathogens, in the doctor's office for quick identification of an infection to assist in prescribing a drug for treatment, and in homes and health centers for inexpensive first-line screening.

The nucleic acid to be detected may be isolated by known methods, or may be detected directly in cells, tissue samples, biological fluids (*e.g.*, saliva, urine, blood, serum), solutions containing PCR components, solutions containing large excesses of oligonucleotides or high molecular weight DNA, and other samples, as also known in the art. See, *e.g.*, Sambrook *et al.*, *Molecular Cloning: A Laboratory Manual* (2nd ed. 1989) and B.D. Hames and S.J. Higgins, Eds., *Gene Probes 1* (IRL Press, New York, 1995). Methods of preparing nucleic acids for detection with hybridizing probes are well known in the art. See, *e.g.*, Sambrook *et al.*, *Molecular Cloning: A Laboratory Manual* (2nd ed. 1989) and B.D. Hames and S.J. Higgins, Eds., *Gene Probes 1* (IRL Press, New York, 1995).

If a nucleic acid is present in small amounts, it may be amplifed by methods known in the art. See, *e.g.*, Sambrook *et al.*, *Molecular Cloning: A Laboratory Manual*

(2nd ed. 1989) and B.D. Hames and S.J. Higgins, Eds., *Gene Probes 1* (IRL Press, New York, 1995). Preferred is polymerase chain reaction (PCR) amplification.

One method according to the invention for detecting nucleic acid comprises contacting a nucleic acid with one or more types of nanoparticles having oligonucleotides attached thereto. The nucleic acid to be detected has at least two portions. The lengths of these portions and the distance(s), if any, between them are chosen so that when the oligonucleotides on the nanoparticles hybridize to the nucleic acid, a detectable change occurs. These lengths and distances can be determined empirically and will depend on the type of particle used and its size and the type of electrolyte which will be present in solutions used in the assay (certain electrolytes affect the conformation of nucleic acids).

Also, when a nucleic acid is to be detected in the presence of other nucleic acids, the portions of the nucleic acid to which the oligonucleotides on the nanoparticles are to bind must be chosen so that they contain sufficient unique sequence so that detection of the nucleic acid will be specific. Guidelines for doing so are well known in the art.

Although nucleic acids may contain repeating sequences close enough to each other so that only one type of oligonucleotide-nanoparticle conjugate need be used, this will be a rare occurrence. In general, the chosen portions of the nucleic acid will have different sequences and will be contacted with nanoparticles carrying two or more different oligonucleotides, preferably attached to different nanoparticles. An example of a system for the detection of nucleic acid is illustrated in Figure 2. As can be seen, a first oligonucleotide attached to a first nanoparticle has a sequence complementary to a first portion of the target

sequence in the single-stranded DNA. A second oligonucleotide attached to a second nanoparticle has a sequence complementary to a second portion of the target sequence in the DNA. Additional portions of the DNA could be targeted with corresponding nanoparticles. See Figure 17. Targeting several portions of a nucleic acid increases the magnitude of the detectable change.

The contacting of the nanoparticle-oligonucleotide conjugates with the nucleic acid takes place under conditions effective for hybridization of the oligonucleotides on the nanoparticles with the target sequence(s) of the nucleic acid. These hybridization conditions are well known in the art and can readily be optimized for the particular system employed. See, *e.g.*, Sambrook *et al.*, *Molecular Cloning: A Laboratory Manual* (2nd ed. 1989). Preferably stringent hybridization conditions are employed.

Faster hybridization can be obtained by freezing and thawing a solution containing the nucleic acid to be detected and the nanoparticle-oligonucleotide conjugates. The solution may be frozen in any convenient manner, such as placing it in a dry ice-alcohol bath for a sufficient time for the solution to freeze (generally about 1 minute for 100 µL of solution). The solution must be thawed at a temperature below the thermal denaturation temperature, which can conveniently be room temperature for most combinations of nanoparticle-oligonucleotide conjugates and nucleic acids. The hybridization is complete, and the detectable change may be observed, after thawing the solution.

The rate of hybridization can also be increased by warming the solution containing the nucleic acid to be detected and the nanoparticle-oligonucleotide conjugates to a temperature below the dissociation temperature (Tm) for the complex formed between the oligonucleotides on

the nanoparticles and the target nucleic acid. Alternatively, rapid hybridization can be achieved by heating above the dissociation temperature (Tm) and allowing the solution to cool.

The rate of hybridization can also be increased by increasing the salt concentration (*e.g.*, from 0.1 M to 0.3 M NaCl).

The detectable change that occurs upon hybridization of the oligonucleotides on the nanoparticles to the nucleic acid may be a color change, the formation of aggregates of the nanoparticles, or the precipitation of the aggregated nanoparticles. The color changes can be observed with the naked eye or spectroscopically. The formation of aggregates of the nanoparticles can be observed by electron microscopy or by nephelometry. The precipitation of the aggregated nanoparticles can be observed with the naked eye or microscopically. Preferred are changes observable with the naked eye. Particularly preferred is a color change observable with the naked eye.

The observation of a color change with the naked eye can be made more readily against a background of a contrasting color. For instance, when gold nanoparticles are used, the observation of a color change is facilitated by spotting a sample of the hybridization solution on a solid white surface (such as silica or alumina TLC plates, filter paper, cellulose nitrate membranes, and nylon membranes, preferably a C-18 silica TLC plate) and allowing the spot to dry. Initially, the spot retains the color of the hybridization solution (which ranges from pink/red, in the absence of hybridization, to purplish-red/purple, if there has been hybridization). On drying at room temperature or 80°C (temperature is not critical), a blue spot develops if the nanoparticle-oligonucleotide conjugates had been

linked by hybridization with the target nucleic acid prior to spotting. In the absence of hybridization (*e.g.*, because no target nucleic acid is present), the spot is pink. The blue and the pink spots are stable and do not change on subsequent cooling or heating or over time. They provide a convenient permanent record of the test. No other steps (such as a separation of hybridized and unhybridized nanoparticle-oligonucleotide conjugates) are necessary to observe the color change.

An alternate method for easily visualizing the assay results would be to spot a sample of nanoparticle probes hybridized to a target nucleic acid on a glass fiber filter (*e.g.*, Borosilicate Microfiber Filter, 0.7 micron pore size, grade FG75, for use with gold nanoparticles 13 nm in size), while drawing the liquid through the filter. Subsequent rinsing with water washes the excess, non-hybridized probes through the filter, leaving behind an observable spot comprising the aggregates generated by hybridization of the nanoparticle probes with the target nucleic acid (retained because these aggregates are larger than the pores of the filter). This technique may provide for greater sensitivity, since an excess of nanoparticle probes can be used. Unfortunately, the nanoparticle probes stick to all other solid surfaces that have been tried (silica slides, reverse-phase plates, and nylon, nitrocellulose, cellulose and other membranes), making glass fiber filters the only solid surface known to date which can be be employed in such a washing format.

An important aspect of the detection system illustrated in Figure 2 is that obtaining a detectable change depends on cooperative hybridization of two different oligonucleotides to a given target sequence in the nucleic acid. Mismatches in either of the two oligonucleotides will destabilize the interparticle

connection. It is well known that a mismatch in base pairing has a much greater destabilizing effect on the binding of a short oligonucleotide probe than on the binding of a long oligonucleotide probe. The advantage of the system illustrated in Figure 2 is that it utilizes the base discrimination associated with a long target sequence and probe (eighteen base-pairs in the example illustrated in Figure 2), yet has the sensitivity characteristic of a short oligonucleotide probe (nine base-pairs in the example illustrated in Figure 2).

The target sequence of the nucleic acid may be contiguous, as in Figure 2, or the two portions of the target sequence may be separated by a third portion which is not complementary to the oligonucleotides on the nanoparticles, as illustrated in Figure 3. In the latter case, one has the option of using a filler oligonucleotide which is free in solution and which has a sequence complementary to that of this third portion (see Figure 3). When the filler oligonucleotide hybridizes with the third portion of the nucleic acid, a double-stranded segment is created, thereby altering the average distance between the nanoparticles and, consequently, the color. The system illustrated in Figure 3 may increase the sensitivity of the detection method.

Some embodiments of the method of detecting nucleic acid utilize a substrate. By employing a substrate, the detectable change (the signal) can be amplified and the sensitivity of the assay increased.

Any substrate can be used which allows observation of the detectable change. Suitable substrates include transparent solid surfaces (*e.g.*, glass, quartz, plastics and other polymers), opaque solid surface (*e.g.*, white solid surfaces, such as TLC silica plates, filter paper, glass fiber filters, cellulose nitrate membranes, nylon membranes), and conducting solid surfaces (*e.g.*, indium-

tin-oxide (ITO)). The substrate can be any shape or thickness, but generally will be flat and thin. Preferred are transparent substrates such as glass (*e.g.*, glass slides) or plastics (*e.g.*, wells of microtiter plates).

In one embodiment, oligonucleotides are attached to the substrate. The oligonucleotides can be attached to the substrates as described in, *e.g.*, Chrisey et al., *Nucleic Acids Res.*, **24**, 3031-3039 (1996); Chrisey et al., *Nucleic Acids Res.*, **24**, 3040-3047 (1996); Mucic et al., *Chem. Commun.*, **555** (1996); Zimmermann and Cox, *Nucleic Acids Res.*, **22**, 492 (1994); Bottomley et al., *J. Vac. Sci. Technol. A*, **10**, 591 (1992); and Hegner et al., *FEBS Lett.*, **336**, 452 (1993).

The oligonucleotides attached to the substrate have a sequence complementary to a first portion of the sequence of the nucleic acid to be detected. The nucleic acid is contacted with the substrate under conditions effective to allow hybridization of the oligonucleotides on the substrate with the nucleic acid. In this manner the nucleic acid becomes bound to the substrate. Any unbound nucleic acid is preferably washed from the substrate before adding nanoparticle-oligonucleotide conjugates.

Next, the nucleic acid bound to the substrate is contacted with a first type of nanoparticles having oligonucleotides attached thereto. The oligonucleotides have a sequence complementary to a second portion of the sequence of the nucleic acid, and the contacting takes place under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the nucleic acid. In this manner the first type of nanoparticles become bound to the substrate. After the nanoparticle-oligonucleotide conjugates are bound to the

substrate, the substrate is washed to remove any unbound nanoparticle-oligonucleotide conjugates and nucleic acid.

The oligonucleotides on the first type of nanoparticles may all have the same sequence or may have different sequences that hybridize with different portions of the nucleic acid to be detected. When oligonucleotides having different sequences are used, each nanoparticle may have all of the different oligonucleotides attached to it or, preferably, the different oligonucleotides are attached to different nanoparticles. Figure 17 illustrates the use of nanoparticle-oligonucleotide conjugates designed to hybridize to multiple portions of a nucleic acid.

Finally, the first type of nanoparticle-oligonucleotide conjugates bound to the substrate is contacted with a second type of nanoparticles having oligonucleotides attached thereto. These oligonucleotides have a sequence complementary to at least a portion of the sequence(s) of the oligonucleotides attached to the first type of nanoparticles, and the contacting takes place under conditions effective to allow hybridization of the oligonucleotides on the first type of nanoparticles with those on the second type of nanoparticles. After the nanoparticles are bound, the substrate is preferably washed to remove any unbound nanoparticle-oligonucleotide conjugates.

The combination of hybridizations produces a detectable change. The detectable changes are the same as those described above, except that the multiple hybridizations result in an amplification of the detectable change. In particular, since each of the first type of nanoparticles has multiple oligonucleotides (having the same or different sequences) attached to it, each of the first type of nanoparticle-oligonucleotide

conjugates can hybridize to a plurality of the second type of nanoparticle-oligonucleotide conjugates. Also, the first type of nanoparticle-oligonucleotide conjugates may be hybridized to more than one portion of the nucleic acid to be detected. The amplification provided by the multiple hybridizations may make the change detectable for the first time or may increase the magnitude of the detectable change. This amplification increases the sensitivity of the assay, allowing for detection of small amounts of nucleic acid.

If desired, additional layers of nanoparticles can be built up by successive additions of the first and second types of nanoparticle-oligonucleotide conjugates. In this way, the number of nanoparticles immobilized per molecule of target nucleic acid can be further increased with a corresponding increase in intensity of the signal.

Also, instead of using first and second types of nanoparticle-oligonucleotide conjugates designed to hybridize to each other directly, nanoparticles bearing oligonucleotides that would serve to bind the nanoparticles together as a consequence of hybridization with binding oligoncleotides could be used.

Methods of making the nanoparticles and the oligonucleotides and of attaching the oligonucleotides to the nanoparticles are described above. The hybridization conditions are well known in the art and can be readily optimized for the particular system employed (see above).

An example of this method of detecting nucleic acid (analyte DNA) is illustrated in Figure 13A. The combination of hybridizations produces dark areas where nanoparticle aggregates are linked to the substrate by analyte DNA. These dark areas may be readily observed with the naked eye using ambient light, preferably viewing the substrate against a white background. As can

be readily seen from Figure 13A, this method provides a means of amplifying a detectable change.

In another embodiment, nanoparticles are attached to the substrate. Nanoparticles can be attached to substrates as described in, *e.g.*, Grabar et al., *Analyt. Chem.*, **67**, 73-743 (1995); Bethell et al., *J. Electroanal. Chem.*, **409**, 137 (1996); Bar et al., *Langmuir*, **12**, 1172 (1996); Colvin et al., *J. Am. Chem. Soc.*, **114**, 5221 (1992).

After the nanoparticles are attached to the substrate, oligonucleotides are attached to the nanoparticles. This may be accomplished in the same manner described above for the attachment of oligonucleotides to nanoparticles in solution. The oligonucleotides attached to the nanoparticles have a sequence complementary to a first portion of the sequence of a nucleic acid.

The substrate is contacted with the nucleic acid under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the nucleic acid. In this manner the nucleic acid becomes bound to the substrate. Unbound nucleic acid is preferably washed from the substrate prior to adding further nanoparticle-oligonucleotide conjugates.

Then, a second type of nanoparticles having oligonucleotides attached thereto is provided. These oligonucleotides have a sequence complementary to a second portion of the sequence of the nucleic acid, and the nucleic acid bound to the substrate is contacted with the second type of nanoparticle-oligonucleotide conjugates under conditions effective to allow hybridization of the oligonucleotides on the second type of nanoparticle-oligonucleotide conjugates with the nucleic acid. In this manner, the second type of nanoparticle-oligonucleotide conjugates becomes bound to

the substrate. After the nanoparticles are bound, any unbound nanoparticle-oligonucleotide conjugates and nucleic acid are washed from the substrate. A change (*e.g.*, color change) may be detectable at this point.

The oligonucleotides on the second type of nanoparticles may all have the same sequence or may have different sequences that hybridize with different portions of the nucleic acid to be detected. When oligonucleotides having different sequences are used, each nanoparticle may have all of the different oligonucleotides attached to it or, preferably, the different oligonucleotides may be attached to different nanoparticles. See Figure 17.

Next, a binding oligonucleotide having a selected sequence having at least two portions, the first portion being complementary to at least a portion of the sequence of the oligonucleotides on the second type of nanoparticles, is contacted with the second type of nanoparticle-oligonucleotide conjugates bound to the substrate under conditions effective to allow hybridization of the binding oligonucleotide to the oligonucleotides on the nanoparticles. In this manner, the binding oligonucleotide becomes bound to the substrate. After the binding oligonucleotides are bound, unbound binding oligonucleotides are washed from the substrate.

Finally, a third type of nanoparticles having oligonucleotides attached thereto is provided. The oligonucleotides have a sequence complementary to the sequence of a second portion of the binding oligonucleotide. The nanoparticle-oligonucleotide conjugates are contacted with the binding oligonucleotide bound to the substrate under conditions effective to allow hybridization of the binding oligonucleotide to the oligonucleotides on the nanoparticles. After the

nanoparticles are bound, unbound nanoparticle-oligonucleotide conjugates are washed from the substrate.

The combination of hybridizations produces a detectable change. The detectable changes are the same as those described above, except that the multiple hybridizations result in an amplification of the detectable change. In particular, since each of the second type of nanoparticles has multiple oligonucleotides (having the same or different sequences) attached to it, each of the second type of nanoparticle-oligonucleotide conjugates can hybridize to a plurality of the third type of nanoparticle-oligonucleotide conjugates (through the binding oligonucleotide). Also, the second type of nanoparticle-oligonucleotide conjugates may be hybridized to more than one portion of the nucleic acid to be detected. The amplification provided by the multiple hybridizations may make the change detectable for the first time or may increase the magnitude of the detectable change. The amplification increases the sensitivity of the assay, allowing for detection of small amounts of nucleic acid.

If desired, additional layers of nanoparticles can be built up by successive additions of the binding oligonucleotides and second and third types of nanoparticle-oligonucleotide conjugates. In this way, the nanoparticles immobilized per molecule of target nucleic acid can be further increased with a corresponding increase in intensity of the signal.

Also, the use of the binding oligonucleotide can be eliminated, and the second and third types of nanoparticle-oligonucleotide conjugates can be designed so that they hybridize directly to each other.

Methods of making the nanoparticles and the oligonucleotides and of attaching the oligonucleotides to the nanoparticles are described above. The hybridization

conditions are well known in the art and can be readily optimized for the particular system employed (see above).

An example of this method of detecting nucleic acid (analyte DNA) is illustrated in Figure 13B. The combination of hybridizations produces dark areas where nanoparticle aggregates are linked to the substrate by analyte DNA. These dark areas may be readily observed with the naked eye as described above. As can be seen from Figure 13B, this embodiment of the method of the invention provides another means of amplifying the detectable change.

Another amplification scheme employs liposomes. In this scheme, oligonucleotides are attached to a substrate. Suitable substrates are those described above, and the oligonucleotides can be attached to the substrates as described above. For instance, where the substrate is glass, this can be accomplished by condensing the oligonucleotides through phosphoryl or carboxylic acid groups to aminoalkyl groups on the substrate surface (for related chemistry see Grabar et al., *Anal. Chem.*, **67**, 735-743 (1995)).

The oligonucleotides attached to the substrate have a sequence complementary to a first portion of the sequence of the nucleic acid to be detected. The nucleic acid is contacted with the substrate under conditions effective to allow hybridization of the oligonucleotides on the substrate with the nucleic acid. In this manner the nucleic acid becomes bound to the substrate. Any unbound nucleic acid is preferably washed from the substrate before adding additional components of the system.

Next, the nucleic acid bound to the substrate is contacted with liposomes having oligonucleotides attached thereto. The oligonucleotides have a sequence complementary to a second portion of the sequence of the

nucleic acid, and the contacting takes place under conditions effective to allow hybridization of the oligonucleotides on the liposomes with the nucleic acid. In this manner the liposomes become bound to the substrate. After the liposomes are bound to the substrate, the substrate is washed to remove any unbound liposomes and nucleic acid.

The oligonucleotides on the liposomes may all have the same sequence or may have different sequences that hybridize with different portions of the nucleic acid to be detected. When oligonucleotides having different sequences are used, each liposome may have all of the different oligonucleotides attached to it or the different oligonucleotides may be attached to different liposomes.

To prepare oligonucleotide-liposome conjugates, the oligonucleotides are linked to a hydrophobic group, such as cholesteryl (see Letsinger et al., *J. Am. Chem. Soc.*, **115**, 7535-7536 (1993)), and the hydrophobic-oligonucleotide conjugates are mixed with a solution of liposomes to form liposomes with hydrophobic-oligonucleotide conjugates anchored in the membrane (see Zhang et al., *Tetrahedron Lett.*, **37**, 6243-6246 (1996)). The loading of hydrophobic-oligonucleotide conjugates on the surface of the liposomes can be controlled by controlling the ratio of hydrophobic-oligonucleotide conjugates to liposomes in the mixture. It has been observed that liposomes bearing oligonucleotides attached by hydrophobic interaction of pendent cholesteryl groups are effective in targeting polynucleotides immobilized on a nitrocellulose membrane (*Id.*). Fluorescein groups anchored in the membrane of the liposome were used as the reporter group. They served effectively, but sensitivity was limited by the fact that the signal from fluorescein

in regions of high local concentration (*e.g.*, on the liposome surface) is weakened by self quenching.

The liposomes are made by methods well known in the art. See Zhang et al., *Tetrahedron Lett.*, **37**, 6243 (1996). The liposomes will generally be about 5-50 times the size (diameter) of the nanoparticles used in subsequent steps. For instance, for nanoparticles about 13 nm in diameter, liposomes about 100 nm in diameter are preferably used.

The liposomes bound to the substrate are contacted with a first type of nanoparticles having at least a first type of oligonucleotides attached thereto. The first type of oligonucleotides have a hydrophobic group attached to the end not attached to the nanoparticles, and the contacting takes place under conditions effective to allow attachment of the oligonucleotides on the nanoparticles to the liposomes as a result of hydrophobic interactions. A detectable change may be observable at this point.

The method may further comprise contacting the first type of nanoparticle-oligonucleotide conjugates bound to the liposomes with a second type of nanoparticles having oligonucleotides attached thereto. The first type of nanoparticles have a second type of oligonucleotides attached thereto which have a sequence complementary to at least a portion of the sequence of the oligonucleotides on the second type of nanoparticles, and the oligonucleotides on the second type of nanoparticles have a sequence complementary to at least a portion of the sequence of the second type of oligonucleotides on the first type of nanoparticles. The contacting takes place under conditions effective to allow hybridization of the oligonucleotides on the first and second types of nanoparticles. This hybridization will generally be performed at mild temperatures (e.g., 5°C to 60°C), so

conditions (*e.g.*, 0.3-1.0 M NaCl) conducive to hybridization at room temperature are employed. Following hybridization, unbound nanoparticle-oligonucleotide conjugates are washed from the substrate.

The combination of hybridizations produces a detectable change. The detectable changes are the same as those described above, except that the multiple hybridizations result in an amplification of the detectable change. In particular, since each of the liposomes has multiple oligonucleotides (having the same or different sequences) attached to it, each of the liposomes can hybridize to a plurality of the first type of nanoparticle-oligonucleotide conjugates. Similarly, since each of the first type of nanoparticles has multiple oligonucleotides attached to it, each of the first type of nanoparticle-oligonucleotide conjugates can hybridize to a plurality of the second type of nanoparticle-oligonucleotide conjugates. Also, the liposomes may be hybridized to more than one portion of the nucleic acid to be detected. The amplification provided by the multiple hybridizations may make the change detectable for the first time or may increase the magnitude of the detectable change. This amplification increases the sensitivity of the assay, allowing for detection of small amounts of nucleic acid.

If desired, additional layers of nanoparticles can be built up by successive additions of the first and second types of nanoparticle-oligonucleotide conjugates. In this way, the number of nanoparticles immobilized per molecule of target nucleic acid can be further increased with a corresponding increase in the intensity of the signal. Further enhancement can also be obtained by employing silver staining of gold nanoparticles (Bassell, et al., *J. Cell Biol.*, **126**, 863-876 (1994); Braun-Howland et al., *Biotechniques*, **13**, 928-931 (1992)).

Also, instead of using second and third types of nanoparticle-oligonucleotide conjugates designed to hybridize to each other directly, nanoparticles bearing oligonucleotides that would serve to bring the nanoparticles together as a consequence of hybridization with binding oligonucleotides could be used.

Methods of making the nanoparticles and the oligonucleotides and of attaching the oligonucleotides to the nanoparticles are described above. A mixture of oligonucleotides functionalized at one end for binding to the nanoparticles and with or without a hydrophobic group at the other end can be used on the first type of nanoparticles. The relative ratio of these oligonucleotides bound to the average nanoparticle will be controlled by the ratio of the concentrations of the two oligonucleotides in the mixture. The hybridization conditions are well known in the art and can be readily optimized for the particular system employed (see above).

An example of this method of detecting nucleic acid is illustrated in Figure 18. The hybridization of the first type of nanoparticle-oligonucleotide conjugates to the liposomes may produce a detectable change. In the case of gold nanoparticles, a pink/red color may be observed or a purple/blue color may be observed if the nanoparticles are close enough together. The hybridization of the second type of nanoparticle-oligonucleotide conjugates to the first type of nanoparticle-oligonucleotide conjugates will produce a detectable change. In the case of gold nanoparticles, a purple/blue color will be observed. All of these color changes may be observed with the naked eye.

When a substrate is employed, a plurality of the initial types of nanoparticle-oligonucleotide conjugates or oligonucleotides can be attached to the substrate in an array for detecting multiple portions of a target

nucleic acid, for detecting multiple different nucleic acids, or both. For instance, a substrate may be provided with rows of spots, each spot containing a different type of oligonucleotide or oligonucleotide-nanoparticle conjugate designed to bind to a portion of a target nucleic acid. A sample containing one or more nucleic acids is applied to each spot, and the rest of the assay is performed in one of the ways described above using appropriate oligonucleotide-nanoparticle conjugates, oligonucleotide-liposome conjugates and binding oligonucleotides.

A nanoparticle-oligonucleotide conjugate which may be used in an assay for any nucleic acid is illustrated in Figure 17, parts IV and V. This "universal probe" has oligonucleotides of a single sequence attached to it. These oligonucleotides can hybridize with a binding oligonucleotide which has a sequence comprising at least two portions. The first portion is complementary to at least a portion of the sequence of the oligonucleotides on the nanoparticles. The second portion is complementary to a portion of the sequence of the nucleic acid to be detected. A plurality of binding oligonucleotides having the same first portion and different second portions can be used, in which case the "universal probe", after hybridization to the binding oligonucleotides, can bind to multiple portions of the nucleic acid to be detected or to different nucleic acid targets.

In yet another embodiment, oligonucleotides attached to metal and semiconductor nanoparticles can have a fluorescent molecule attached to the end not attached to the nanoparticles. Metal and semiconductor nanoparticles are known fluorescence quenchers, with the magnitude of the quenching effect depending on the distance between the nanoparticles and the fluorescent molecule. In the

unhybridized state, the oligonucleotides attached to the nanoparticles interact with the nanoparticles, so that significant quenching will be observed. See Figure 20A. Upon hybridization to a target nucleic acid, the fluorescent molecule will become spaced away from the nanoparticles, diminishing quenching of the fluorescence. See Figure 20A. Longer oligonucleotides should give rise to larger changes in fluorescence, at least until the fluorescent groups are moved far enough away from the nanoparticle surfaces so that an increase in the change is no longer observed. Useful lengths of the oligonucleotides can be determined empirically. Metallic and semiconductor nanoparticles having fluorescent-labeled oligonucleotides attached thereto can be used in any of the assay formats described above, including those performed in solution or on substrates.

Methods of labeling oligonucleotides with fluorescent molecules and measuring fluorescence are well known in the art. Suitable fluorescent molecules are also well known in the art and include the fluoresceins, rhodamines and Texas Red. The oligonucleotides will be attached to the nanoparticles as described above.

In yet another embodiment, two types of fluorescent-labeled oligonucleotides attached to two different particles can be used. Suitable particles include polymeric particles, such as polystyrene particles, polyvinyl particles, acrylate and methacrylate particles, glass particles, latex particles, Sepharose beads and others like particles well known in the art. Methods of attaching oligonucleotides to such particles are well known in the art. In particular, a wide variety of functional groups are availble on the particles or can be incorporated into such particles. Functional groups include carboxylic acids, aldehydes, amino groups, cyano groups, ethylene groups, hydroxyl groups, mercapto

groups, and the like. Nanoparticles, including metallic and semiconductor nanoparticles can also be used.

The two fluorophores are designated **d** and **a** for donor and acceptor. A variety of fluorescent molecules useful in such combinations are well known in the art and are available from, *e.g.*, Molecular Probes. An attractive combination is fluorescein as the donor and Texas Red as acceptor. The two types of nanoparticle-oligonucleotide conjugates with **d** and **a** attached are mixed with the target nucleic acid, and fluorescence measured in a fluorimeter. The mixture will be excited with light of the wavelength that excites **d**, and the mixture will be monitored for fluorescence from a. Upon hybridization, **d** and **a** will be brought in proximity (see Figure 20B).

In the case of non-metallic, non-semiconductor particles, hybridization will be shown by a shift in fluorescence from that for **d** to that for **a** or by the appearance of fluorescence for a in addition to that for **d**. In the absence of hybridization, the flurophores will be too far apart for energy transfer to be significant, and only the fluorescence of **d** will be observed.

In the case of metallic and semiconductor nanoparticles, lack of hybridization will be shown by a lack of fluorescence due to **d** or **a** because of quenching (see above). Hybridization will be shown by an increase in fluorescence due to **a**.

As will be appreciated, the above described particles and nanoparticles having oligonucleotides labeled with acceptor and donor fluorescent molecules attached can be be used in the assay formats described above, including those performed in solution and on substrates. For solution formats, the oligonucleotide

sequences are preferably chosen so that they bind to the target nucleic acid as illustrated in Figure 15. In the formats shown in Figure 13A-B and 18, the binding oligonucleotides may be used to bring the acceptor and donor fluorescent molecules on the two nanoparticles in proximity. Also, in the format illustrated in Figure 13A, the oligonucleotides attached the substrate may be labeled with **d**. Further, in principle, other labels besides fluorescent molecules can be used, such as chemiluminescent molecules, which will give a detectable signal or a change in detectable signal upon hybridization.

The invention also provides kits for detecting nucleic acids. In one embodiment, the kit comprises at least one container, the container holding at least two types of nanoparticles having oligonucleotides attached thereto. The oligonucleotides on the first type of nanoparticles have a sequence complementary to the sequence of a first portion of a nucleic acid. The oligonucleotides on the second type of nanoparticles have a sequence complementary to the sequence of a second portion of the nucleic acid. The container may further comprise filler oligonucleotides having a sequence complementary to a third portion of the nucleic acid, the third portion being located between the first and second portions. The filler oligonucleotide may also be provided in a separate container.

In a second embodiment, the kit comprises at least two containers. The first container holds nanoparticles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid. The second container holds nanoparticles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a second portion of the nucleic acid. The kit may further

comprise a third container holding a filler oligonucleotide having a sequence complementary to a third portion of the nucleic acid, the third portion being located between the first and second portions.

In another alternative embodiment, the kits can have the oligonucleotides and nanoparticles in separate containers, and the oligonucleotides would have to be attached to the nanoparticles prior to performing an assay to detect a nucleic acid. The oligonucleotides and/or the nanoparticles may be functionalized so that the oligonucleotides can be attached to the nanoparticles. Alternatively, the oligonucleotides and/or nanoparticles may be provided in the kit without functional groups, in which case they must be functionalized prior to performing the assay.

In another embodiment, the kit comprises at least one container. The container holds metallic or semiconductor nanoparticles having oligonucleotides attached thereto. The oligonucleotides have a sequence complementary to a portion of a nucleic acid and have fluorescent molecules attached to the ends of the oligonucleotides not attached to the nanoparticles.

In yet another embodiment, the kit comprises a substrate, the substrate having attached thereto nanoparticles. The nanoparticles have oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid. The kit also includes a first container holding nanoparticles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a second portion of the nucleic acid. The oligonucleotides may have the same or different sequences, but each of the oligonucleotides has a sequence complementary to a portion of the nucleic acid. The kit further includes a second container holding a binding oligonucleotide having

a selected sequence having at least two portions, the first portion being complementary to at least a portion of the sequence of the oligonucleotides on the nanoparticles in the first container. The kit also includes a third container holding nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to the sequence of a second portion of the binding oligonucleotide.

In another embodiment, the kit comprises a substrate having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid. The kit also includes a first container holding nanoparticles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a second portion of the nucleic acid. The oligonucleotides may have the same or different sequences, but each of the oligonucleotides has a sequence complementary to a portion of the nucleic acid. The kit further includes a second container holding nanoparticles having oligonucleotides attached thereto which have a sequence complementary to at least a portion of the oligonucleotides attached to the nanoparticles in the first container.

In yet another embodiment, the kits can have the substrate, oligonucleotides and nanoparticles in separate containers. The substrate, oligonucleotides, and nanoparticles would have to be appropriately attached to each other prior to performing an assay to detect a nucleic acid. The substrate, oligonucleotides and/or the nanoparticles may be functionalized to expedite this attachment. Alternatively, the substrate, oligonucleotides and/or nanoparticles may be provided in the kit without functional groups, in which case they must be functionalized prior to performing the assay.

In a further embodiment, the kit comprises a substrate having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid. The kit also includes a first container holding liposomes having oligonucleotides attached thereto which have a sequence complementary to the sequence of a second portion of the nucleic acid and a second container holding nanoparticles having at least a first type of oligonucleotides attached thereto, the first type of oligonucleotides having a cholesteryl group attached to the end not attached to the nanoparticles so that the nanoparticles can attach to the liposomes by hydrophobic interactions. The kit may further comprise a third container holding a second type of nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to at least a portion of the sequence of a second type of oligonucleotides attached to the first type of nanoparticles. The second type of oligonucleotides attached to the first type of nanoparticles have a sequence complementary to the sequence of the oligonucleotides on the second type of nanoparticles.

In a further embodiment, the kit may comprise a first container holding nanoparticles having oligonucleotides attached thereto. The kit also includes one or more additional containers, each container holding a binding oligonucleotide. Each binding oligonucleotide has a first portion which has a sequence complementary to at least a portion of the sequence of oligonucleotides on the nanoparticles and a second portion which has a sequence complementary to the sequence of a portion of a nucleic acid to be detected. The sequences of the second portions of the binding oligonucleotides may be different as long as each sequence is complementary to a portion of the sequence of the nucleic acid to be detected.

In another embodiment, the kit comprises a container holding one type of nanoparticles having oligonucleotides attached thereto and one or more types of binding oligonucleotides. Each of the types of binding oligonucleotides has a sequence comprising at least two portions. The first portion is complementary to the sequence of the oligonucleotides on the nanoparticles, whereby the binding oligonucleotides are hybridized to the oligonucleotides on the nanoparticles in the container(s). The second portion is complementary to the sequence of a portion of the nucleic acid.

In another embodiment, kits may comprise one or two containers holding two types of particles. The first type of particles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid. The oligonucleotides are labeled with an energy donor on the ends not attached to the particles. The second type of particles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a second portion of a nucleic acid. The oligonucleotides are labeled with an energy acceptor on the ends not attached to the particles. The energy donors and acceptors may be fluorescent molecules.

The kits may also contain other reagents and items useful for detecting nucleic acid. The reagents may include PCR reagents, hybridization reagents, buffers, etc. Other items which may be provided as part of the kit include a solid surface (for visualizing hybridization) such as a TLC silica plate, syringes, pipettes, cuvettes, containers, and a thermocycler (for controlling hybridization and de-hybridization temperatures). Reagents for functionalizing the nucleotides or nanoparticles may also be included in the kit.

The precipitation of aggregated nanoparticles provides a means of separating a selected nucleic acid from other nucleic acids. This separation may be used as a step in the purification of the nucleic acid. Hybridization conditions are those described above for detecting a nucleic acid. If the temperature is below the Tm (the temperature at which one-half of an oligonuceotide is bound to its complementary strand) for the binding of the oligonucleotides on the nanoparticles to the nucleic acid, then sufficient time is needed for the aggregate to settle. The temperature of hybridization (*e.g.*, as measured by Tm) varies with the type of salt (NaCl or $MgCl_2$) and its concentration. Salt compositions and concentrations are selected to promote hybridization of the oligonucleotides on the nanoparticles to the nucleic acid at convenient working temperatures without inducing aggregation of the colloids in the absence of the nucleic acid.

The invention also provides a method of nanofabrication. The method comprises providing at least one type of linking oligonucleotide having a selected sequence. A linking oligonucleotide used for nanofabrication may have any desired sequence and may be single-stranded or double-stranded. It may also contain chemical modifications in the base, sugar, or backbone sections. The sequences chosen for the linking oligonucleotides and their lengths and strandedness will contribute to the rigidity or flexibility of the resulting nanomaterial or nanostructure, or a portion of the nanomaterial or nanostructure. The use of a single type of linking oligonucleotide, as well as mixtures of two or more different types of linking oligonucleotides, is contemplated. The number of different linking oligonucleotides used and their lengths will contribute

to the shapes, pore sizes and other structural features of the resulting nanomaterials and nanostructures.

The sequence of a linking oligonucleotide will have at least a first portion and a second portion for binding to oligonucleotides on nanoparticles. The first, second or more binding portions of the linking oligonucleotide may have the same or different sequences.

If all of the binding portions of a linking oligonucleotide have the same sequence, only a single type of nanoparticle with oligonucleotides having a complementary sequence attached thereto need be used to form a nanomaterial or nanostructure. If the two or more binding portions of a linking oligonucleotide have different sequences, then two or more nanoparticle-oligonucleotide conjugates must be used. *See, e.g.*, Figure 17. The oligonucleotides on each of the nanoparticles will have a sequence complementary to one of the two or more binding portions of the sequence of the linking oligonucleotide The number, sequence(s) and length(s) of the binding portions and the distance(s), if any, between them will contribute to the structural and physical properties of the resulting nanomaterials and nanostructures. Of course, if the linking oligonucleotide comprises two or more portions, the sequences of the binding portions must be chosen so that they are not complementary to each other to avoid having one portion of the linking nucleotide bind to another portion.

The linking oligonucleotides and nanoparticle-oligonucleotide conjugates are contacted under conditions effective for hybridization of the oligonucleotides attached to the nanoparticles with the linking oligonucleotides so that a desired nanomaterial or nanostructure is formed wherein the nanoparticles are held together by oligonucleotide connectors. These

hybridization conditions are well known in the art and can be optimized for a particular nanofabrication scheme (see above). Stringent hybridization conditions are preferred.

The invention also provides another method of nanofabrication. This method comprises providing at least two types of nanoparticle-oligonucleotide conjugates. The oligonucleotides on the first type of nanoparticles have a sequence complementary to that of the oligonucleotides on the second type of nanoparticles. The oligonucleotides on the second type of nanoparticles have a sequence complementary to that of the oligonucleotides on the first type of nanoparticles. The nanoparticle-oligonucleotide conjugates are contacted under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles to each other so that a desired nanomaterial or nanostructure is formed wherein the nanoparticles are held together by oligonucleotide connectors. Again, these hybridization conditions are well-known in the art and can be optimized for a particular nanofabrication scheme.

In both nanofabrication methods of the invention, the use of nanoparticles having one or more different types of oligonucleotides attached thereto is contemplated. The number of different oligonucleotides attached to a nanoparticle and the lengths and sequences of the one or more oligonucleotides will contribute to the rigidity and structural features of the resulting nanomaterials and nanostructures.

Also, the size, shape and chemical composition of the nanoparticles will contribute to the properties of the resulting nanomaterials and nanostructures. These properties include optical properties, optoelectronic properties, stability in various solutions, pore and channel size variation, ability to separate bioactive

molecules while acting as a filter, etc. The use of mixtures of nanoparticles having different sizes, shapes and/or chemical compositions, as well as the use of nanoparticles having uniform sizes, shapes and chemical composition, are contemplated.

In either fabrication method, the nanoparticles in the resulting nanomaterial or nanostructure are held together by oligonucleotide connectors. The sequences, lengths, and strandedness of the oligonucleotide connectors, and the number of different oligonucleotide connectors present will contribute to the rigidty and structural properties of the nanomaterial or nanostructure. If an oligonucleotide connector is partially double-stranded, its rigidity can be increased by the use of a filler oligonucleotide as described above in connection with the method of detecting nucleic acid. The rigidity of a completely double-stranded oligonucleotide connector can be increased by the use of one or more reinforcing oligonucleotides having complementary sequences so that they bind to the double-stranded oligonucleotide connector to form triple-stranded oligonucleotide connectors. The use of quadruple-stranded oligonucleotide connectors based on deoxyquanosine or deoxycytidine quartets is also contemplated.

Several of a variety of systems for organizing nanoparticles based on oligonucleotide hybridization are illustrated in the figures. In a simple system (Figure 1) one set of nanoparticles bears oligonucleotides with a defined sequence and another set of nonoparticles bears oligonucleotides with a complementary sequence. On mixing the two sets of nanoparticle-oligonucleotide conjugates under hybridization conditions, the two types of particles are linked by double stranded

oligonucleotide connectors which serve as spacers to position the nanoparticles at selected distances.

An attractive system for spacing nanoparticles involves the addition of one free linking oligonucleotide as illustrated in Figure 2. The sequence of the linking oligonucleotide will have at least a first portion and a second portion for binding to oligonucleotides on nanoparticles. This system is basically the same as utilized in the nucleic acid detection method, except that the length of the added linking oligonucleotide can be selected to be equal to the combined lengths of oligonucleotides attached to the nanoparticles. The related system illustrated in Figure 3 provides a convenient means to tailor the distance between nanoparticles without having to change the sets of nanoparticle-oligonucleotide conjugates employed.

A further elaboration of the scheme for creating defined spaces between nanoparticles is illustrated in Figure 4. In this case a double stranded segment of DNA or RNA containing overhanging ends is employed as the linking oligonucleotide. Hybridization of the single-stranded, overhanging segments of the linking oligonucleotide with the oligonucleotides attached to the nanoparticles affords multiple double-stranded oligonucleotide cross-links between the nanoparticles.

Stiffer nanomaterials and nanostructures, or portions thereof, can be generated by employing triple-stranded oligonucleotide connectors between nanoparticles. In forming the triple strand, one may exploit either the pyrimidine:purine:pyrimidine motif (Moser, H.E. and Dervan, P.B. *Science,* 238, 645-650 (1987) or the purine:purine:pyrimidine motif (Pilch, D.S. et al. *Biochemistry,* 30, 6081-6087 (1991). An example of the organization of nanoparticles by generating triple-stranded connectors by the pyrimidine:purine:pyrimidine

motif are illustrated in Figure 10. In the system shown in Figure 10, one set of nanoparticles is conjugated with a defined strand containing pyrimidine nucleosides and the other set is conjugated with a complementary oligonucleotide containing purine nucleosides. Attachment of the oligonucleotides is designed such that the nanoparticles are separated by the double-stranded oligonucleotide formed on hybridization. Then, a free pyrimidine oligonucleotide with an orientation opposite that for the pyrimidine strand linked to the nanoparticle is added to the system prior to, simultaneously with, or just subsequent to mixing the nanoparticles. Since the third strand in this system is held by Hoogsteen base pairing, the triple strand is relatively unstable thermally. Covalent bridges spanning the breadth of the duplex are known to stabilize triple-stranded complexes (Salunke, M., Wu, T., Letsinger, R.L., *J. Am, Chem. Soc.* **114**, 8768-8772, (1992). Letsinger, R.L. and Wu, T. *J. Am Chem. Soc.*, **117**, 7323-7328 (1995). Prakash, G. and Kool, *J. Am. Chem. Soc.*, **114**, 3523-3527 (1992).

For construction of nanomaterials and nanostructures, it may be desirable in some cases to "lock" the assembly in place by covalent cross-links after formation of the nanomaterial or nanostructure by hybridization of the oligonucleotide components. This can be accomplished by incorporating functional groups that undergo a triggered irreversible reaction into the oligonucleotides. An example of a functional group for this purpose is a stilbenedicarboxamide group. It has been demonstrated that two stilbenedicarboxamide groups aligned within hybridized oligonucleotides readily undergo cross-linking on irradiation with ultraviolet light (340 nm) (Lewis, F.D. et al. (1995) *J Am. Chem. Soc.* **117**, 8785-8792).

Alternatively, one could employ the displacement of a 5'-O-tosyl group from an oligonucleotide, held at the 3'-position to a nanoparticle by a mercaptoalkly group, with a thiophosphoryl group at the 3'-end of an oligonucleotide held to an nanoparticle by a mercaptoalkyl group. In the presence of an oligonucleotide that hybridizes to both oligonucleotides and, thereby, brings the thiophosphoryl group into proximity of the tosyl group, the tosyl group will be displaced by the thiophosphoryl group, generating an oligonucleotide linked at the ends to two different nanoparticles. For displacement reactions of this type, see Herrlein et al., *J. Am. Chem. Soc.*, **177**, 10151-10152 (1995). The fact that thiophosphoryl oligonucleotides do not react with gold nanoparticles under the conditions employed in attaching mercaptoalkyl-oligonucleotides to gold nanoparticles enables one to prepare gold nanoparticle-oligonucleotide conjugates anchored through the mercapto group to the nanoparticles and containing a terminal thiophosphoryl group free for the coupling reaction.

A related coupling reaction to lock the assembled nanoparticle system in place utilizes displacement of bromide from a terminal bromoacetylaminonucleoside by a terminal thiophosphoryl-oligonucleotide as described in Gryaznov and Letsinger, *J. Am. Chem. Soc.*, **115**, 3808. This reaction proceeds much like the displacement of tosylate described above, except that the reaction is faster. Nanoparticles bearing oligonucleotides terminated with thiophosphoryl groups are prepared as described above. For preparation of nanoparticles bearing oligonucleotides terminated with bromoacetylamino groups, one first prepares an oligonucleotide terminated at one end by an aminonucleoside (*e.g.*, either 5'-amino-5'-deoxythymidine or 3'-amino-3'-deoxythymidine) and at

the other end by a mercaptoalkyl group. Molecules of this oligoncleotide are then anchored to the nanoparticles through the mercapto groups, and the nanoparticle-oligonucleotide conjugate is then converted the N-bromoacetylamino derivative by reaction with a bromoacetyl acylating agent.

A fourth coupling scheme to lock the assemblies in place utilizes oxidation of nanoparticles bearing oligonucleotides terminated by thiophosphoryl groups. Mild oxidizing agents, such as potassium triiodide, potassium ferricyanide (see Gryaznov and Letsinger, *Nucleic Acids Research*, **21**, 1403) or oxygen, are preferred.

In addition, the properties of the nanomaterials and nanostructures can be altered by incorporating into the interconnecting oligonucleotide chains organic and inorganic functions that are held in place by covalent attachment to the oligonucleotide chains. A wide variety of backbone, base and sugar modifications are well known (see for example Uhlmann, E., and Peyman, A. *Chemical Reviews*, **90**, 544-584 (1990). Also, the oligonucleotide chains could be replaced by "Peptide Nucleic Acid" chains (PNA), in which the nucleotide bases are held by a polypeptide backbone (see Wittung, P. et al., *Nature*, **368**, 561-563 (1994).

As can be seen from the foregoing, the nanofabrication method of the invention is extremely versatile. By varying the length, sequence and strandedness of the linking oligonucleotides, the number, length, and sequence of the binding portions of the linking oligonucleotides, the length, sequence and number of the oligonucleotides attached to the nanoparticles, the size, shape and chemical composition of the nanoparticles, the number and types of different linking oligonucleotides and nanoparticles used, and the

strandedness of the oligonucleotide connectors, nanomaterials and nanostructures having a wide range of structures and properties can be prepared. These structures and properties can be varied further by cross-linking of the oligonucleotide connectors, by functionalizing the oligonucleotides, by backbone, base or sugar modifications of the oligonucleotides, or by the use of peptide-nucleic acids.

The nanomaterials and nanostructures that can be made by the nanofabrication method of the invention include nanoscale mechanical devices, separation membranes, bio-filters, and biochips. It is contemplated that the nanomaterials and nanostructures of the invention can be used as chemical sensors, in computers, for drug delivery, for protein engineering, and as templates for biosynthesis/nanostructure fabrication/directed assembly of other structures. See generally Seeman et al., *New J. Chem.*, **17**, 739 (1993) for other possible applications.

It is to be noted that the term "a" or "an" entity refers to one or more of that entity. For example, "a characteristic" refers to one or more characteristics or at least one characteristic. As such, the terms "a" (or "an"), "one or more" and "at least one" are used interchangeably herein. It is also to be noted that the terms "comprising", "including", and "having" have been used interchangeably.

EXAMPLES

Example 1: Preparation of Oligonucleotide-Modified Gold Nanoparticles

A. Preparation Of Gold Nanoparticles

Gold colloids (13 nm diameter) were prepared by reduction of $HAuCl_4$ with citrate as described in Frens, *Nature Phys. Sci.*, **241**, 20 (1973) and Grabar, *Anal. Chem.*, **67**, 735 (1995). Briefly, all glassware was cleaned in aqua regia (3 parts HCl, 1 part HNO_3), rinsed with Nanopure H_2O, then oven dried prior to use. $HAuCl_4$ and sodium citrate were purchased from Aldrich Chemical Company. Aqueous $HAuCl_4$ (1 mM, 500 mL) was brought to reflux while stirring. Then, 38.8 mM sodium citrate (50 mL) was added quickly. The solution color changed from pale yellow to burgundy, and refluxing was continued for 15 min. After cooling to room temperature, the red solution was filtered through a Micron Separations Inc. 1 micron filter. Au colloids were characterized by UV-vis spectroscopy using a Hewlett Packard 8452A diode array spectrophotometer and by Transmission Electron Microscopy (TEM) using a Hitachi 8100 transmission electron microscope. Gold particles with diameters of 13 nm will produce a visible color change when aggregated with target and probe oligonucleotide sequences in the 10-35 nucleotide range.

B. Synthesis Of Oligonucleotides

Oligonucleotides were synthesized on a 1 micromole scale using a Milligene Expedite DNA synthesizer in single column mode using phosphoramidite chemistry. Eckstein, F. (ed.) *Oligonucleotides and Analogues: A Practical Approach* (IRL Press, Oxford, 1991). All solutions were purchased from Milligene (DNA synthesis

grade). Average coupling efficiency varied from 98 to 99.8%, and the final dimethoxytrityl (DMT) protecting group was not cleaved from the oligonucleotides to aid in purification.

For 3'-thiol-oligonucleotides, Thiol-Modifier C3 S-S CPG support was purchased from Glen Research and used in the automated synthesizer. During normal cleavage from the solid support (16 hr at 55° C), 0.05 M dithiothreitol (DTT) was added to the NH_4OH solution to reduce the 3' disulfide to the thiol. Before purification by reverse phase high pressure liquid chromatography (HPLC), excess DTT was removed by extraction with ethyl acetate.

For 5'-thiol oligonucleotides, 5'-Thiol-Modifier C_6-phosphoramidite reagent was purchased from Glen Research, 44901 Falcon Place, Sterling, Va 20166. The oligonucleotides were synthesized, and the final DMT protecting group removed. Then, 1 ml of dry acetonitrile was added to 100 µmole of the 5' Thiol Modifier C_6-phosphoramidite. 200 µL of the amidite solution and 200 µL of activator (fresh from synthesizer) were mixed and introduced onto the column containing the synthesized oligonucleotides still on the solid support by syringe and pumped back and forth through the column for 10 minutes. The support was then washed (2 x 1 mL) with dry acetonitrile for 30 seconds. 700 µL of a 0.016 M I_2/H_2O/pyridine mixture (oxidizer solution) was introduced into the column, and was then pumped back and forth through the column with two syringes for 30 second. The support was then washed with a 1:1 mixture of CH_3CN/pyridine (2 x 1 mL) for 1 minute, followed by a final wash with dry acetonitrile (2 x 1 mL) with subsequent drying of the column with a stream of nitrogen. The trityl protecting group was not removed, which aids in purification.

Reverse phase HPLC was performed with a Dionex DX500 system equipped with a Hewlett Packard ODS hypersil column (4.6 x 200 mm, 5 mm particle size) using 0.03 M Et_3NH^+ OAc^- buffer (TEAA), pH 7, with a 1%/min. gradient of 95% CH_3CN/5% TEAA. The flow rate was 1 mL/ min. with UV detection at 260 nm. Preparative HPLC was used to purify the DMT-protected unmodified oligonucleotides (elution at 27 min). After collection and evaporation of the buffer, the DMT was cleaved from the oligonucleotides by treatment with 80% acetic acid for 30 min at room temperature. The solution was then evaporated to near dryness, water was added, and the cleaved DMT was extracted from the aqueous oligonucleotide solution using ethyl acetate. The amount of oligonucleotide was determined by absorbance at 260 nm, and final purity assessed by reverse phase HPLC (elution time 14.5 minutes).

The same protocol was used for purification of the 3'-thiol-oligonucleotides, except that DTT was added after extraction of DMT to reduce the amount of disulfide formed. After six hours at 40°C, the DTT was extracted using ethyl acetate, and the oligonucleotides repurified by HPLC (elution time 15 minutes).

For purification of the 5' thiol modified oligonucleotides, preparatory HPLC was performed under the same conditions as for unmodified oligonucleotides. After purification, the trityl protecting group was removed by adding 150 µL of a 50 mM $AgNO_3$ solution to the dry oligonucleotide sample. The sample turned a milky white color as the cleavage occurred. After 20 minutes, 200 µL of a 10 mg/ml solution of DTT was added to complex the Ag (five minute reaction time), and the sample was centrifuged to precipitate the yellow complex. The oligonucleotide solution (<50 OD) was then transferred onto a desalting NAP-5 column (Pharmacia Biotech,

Uppsala, Sweden) for purification (contains DNA Grade Sephadex G-25 Medium for desalting and buffer exchange of oligonucleotides greater than 10 bases). The amount of 5' thiol modified oligonucleotide was determined by UV-vis spectroscopy by measuring the magnitude of the absorbance at 260 nm. The final purity was assessed by performing ion-exchange HPLC with a Dionex Nucleopac PA-100 (4 x 250) column using a 10 mM NaOH solution (pH 12) with a 2%/min gradient of 10 mM NaOH, 1M NaCl solution. Typically, two peaks resulted with elution times of approximately 19 minutes and 25 minutes (elution times are dependent on the length of the oligonucleotide strand). These peaks corresponded to the thiol and the disulfide oligonucleotides respectively.

C. Attachment Of Oligonucleotides To Gold Nanoparticles

An aqueous solution of 17nM (150 μL) Au colloids, prepared as described in part A above, was mixed with 3.75 μM (46 μL) 3'-thiol-TTTGCTGA, prepared as described in part B and allowed to stand for 24 hours at room temperature in 1 ml Eppendorf capped vials. A second solution of colloids was reacted with 3.75 μM (46 μL) 3'-thiol-TACCGTTG. Note that these oligonucleotides are noncomplementary. Shortly before use, equal amounts of each of the two nanoparticle solutions were combined. Since the oligonucleotides are noncomplementary, no reaction took place.

The oligonucleotide-modified nanoparticles are stable at elevated temperatures (80°C) and high salt concentrations (1M NaCl) for days and have not been observed to undergo particle growth. Stability in high salt concentrations is important, since such conditions are required for the hybridization reactions that form the basis of the methods of detection and nanofabrication of the invention.

Example 2: Formation Of Nanoparticle Aggregates

A. Preparation Of Linking Oligonucleotide

Two (nonthiolated) oligonucleotides were synthesized as described in part B of Example 1. They had the following sequences:

3' ATATGCGCGA TCTCAGCAAA [SEQ ID NO:1]; and

3' GATCGCGCAT ATCAACGGTA [SEQ ID NO:2].

Mixing of these two oligonucleotides in a 1 M NaCl, 10 mM phosphate buffered (pH 7.0) solution, resulted in hybridization to form a duplex having a 12-base-pair overlap and two 8-base-pair sticky ends. Each of the sticky ends had a sequence which was complementary to that of one of the oligonucleotides attached to the Au colloids prepared in part C of Example 1.

B. Formation Of Nanoparticle Aggregates

The linking oligonucleotides prepared in part A of this example (0.17 μM final concentration after dilution with NaCl) were added to the nanoparticle-oligonucleotide conjugates prepared in part C of Example 1 (5.1 nM final concentration after dilution with NaCl) at room temperature. The solution was then diluted with aqueous NaCl (to a final concentration of 1 M) and buffered at pH 7 with 10 mM phosphate, conditions which are suitable for hybridization of the oligonucleotides. An immediate color change from red to purple was observed, and a precipitation reaction ensued. See Figure 6. Over the course of several hours, the solution became clear and a pinkish-gray precipitate settled to the bottom of the reaction vessel. See Figure 6.

To verify that this process involved both the oligonucleotides and colloids, the precipitate was collected and resuspended (by shaking) in 1 M aqueous NaCl buffered at pH 7. Any of the oligonucleotides not hybridized to the nanoparticles are removed in this

manner. Then, a temperature/time dissociation experiment was performed by monitoring the characteristic absorbance for the hybridized oligodeoxyribonucleotides (260 nm) and for the aggregated colloids which is reflective of the gold interparticle distance (700 nm). See Figure 7. Changes in absorbance at 260 and 700 nm were recorded on a Perkin-Elmer Lambda 2 UV-vis Spectrophotometer using a Peltier PTP-1 Temperature Controlled Cell Holder while cycling the temperature at a rate of 1°C/minute between 0°C and 80°C. DNA solutions were approximately 1 absorbance unit(s) (OD), buffered at pH 7 using 10 mM phosphate buffer and at 1M NaCl concentration.

The results are shown in Figure 8A. As the temperature was cycled between 0°C and 80°C (which is 38°C above the dissociation temperature (T_m) for the duplex (T_m=42 °C)), there was an excellent correlation between the optical signatures for both the colloids and oligonucleotides. The UV-vis spectrum for naked Au colloids was much less temperature dependent, Figure 8B.

There was a substantial visible optical change when the polymeric oligonucleotide-colloid precipitate was heated above its melting point. The clear solution turned dark red as the polymeric biomaterial de-hybridized to generate the unlinked colloids which are soluble in the aqueous solution. The process was reversible, as evidenced by the temperature traces in Figure 8A.

In a control experiment, a 14-T:14-A duplex was shown to be ineffective at inducing reversible Au colloid particle aggregation. In another control experiment, a linking oligonucleotide duplex with four base pair mismatches in the sticky ends was found not to induce reversible particle aggregation of oligonucleotide-modified nanoparticles (prepared as described in part C of Example 1 and reacted as described above). In a third

control experiment, non-thiolated oligonucleotides having sequences complementary to the sticky ends of the linking oligonucleotide and reacted with nanoparticles did not produce reversible aggregation when the nanoparticles were combined with the linking oligonucleotide.

Further evidence of the polymerization/assembly process came from Transmission Electron Microscopy (TEM) studies of the precipitate. TEM was performed on a Hitachi 8100 Transmission Electron Microscope. A typical sample was prepared by dropping 100 μL of colloid solution onto a holey carbon grid. The grid, then, was dried under vacuum and imaged. TEM images of Au colloids linked by hybridized oligonucleotides showed large assembled networks of the Au colloids, Figure 9A. Naked Au colloids do not aggregate under comparable conditions but rather disperse or undergo particle growth reactions. Hayat, *Colloidal Gold: Principles, Methods, and Applications* (Academic Press, San Diego, 1991). Note that there is no evidence of colloid particle growth in the experiments performed to date; the hybridized colloids seem to be remarkably regular in size with an average diameter of 13 nm.

With TEM, a superposition of layers is obtained, making it difficult to assess the degree of order for three-dimensional aggregates. However, smaller scale images of single layer, two-dimensional aggregates provided more evidence for the self-assembly process, Figure 9B. Close-packed assemblies of the aggregates with uniform particle separations of approximately 60 Å can be seen. This distance is somewhat shorter than the estimated 95 Å spacing expected for colloids connected by rigid oligonucleotide hybrids with the sequences that were used. However, because of the nicks in the duplex obtained after hybridization of the oligonucleotides on the nanoparticles to the linking oligonucleotides, these

were not rigid hybrids and were quite flexible. It should be noted that this is a variable that can be controlled by reducing the system from four overlapping strands to three (thereby reducing the number of nicks) or by using triplexes instead of duplexes.

Example 3: Preparation of Oligonucleotide-Modified Gold Nanoparticles

Gold colloids (13 nm diameter) were prepared as described in Example 1. Thiol-oligonucleotides [$HS(CH_2)_6OP(O)(O^-)$-oligonucleotide] were also prepared as described in Example 1.

The method of attaching thiol-oligonucleotides to gold nanoparticles described in Example 1 was found not to produce satisfactory results in some cases. In particular, when long oligonucleotides were used, the oligonucleotide-colloid conjugates were not stable in the presence of a large excess of high molecular weight salmon sperm DNA used as model for the background DNA that would normally be present in a diagnostic system. Longer exposure of the colloids to the thiol-oligonucleotides produced oligonucleotide-colloid conjugates that were stable to salmon sperm DNA, but the resulting conjugates failed to hybridize satisfactorily. Further experimentation led to the following procedure for attaching thiol-oligonucleotides of any length to gold colloids so that the conjugates are stable to high molecular weight DNA and hybridize satisfactorily.

A 1 mL solution of the gold colloids (17nM) in water was mixed with excess (3.68 μM) thiol-oligonucleotide (28 bases in length) in water, and the mixture was allowed to stand for 12-24 hours at room temperature. Then, 100 μL of a 0.1 M sodium hydrogen phosphate buffer, pH 7.0, and 100 μL of 1.0 M NaCl were premixed and added. After 10 minutes, 10 μL of 1% aqueous NaN_3 were added, and the

mixture was allowed to stand for an additional 40 hours. This "aging" step was designed to increase the surface coverage by the thiol-oligonucleotides and to displace oligonucleotide bases from the gold surface. Somewhat cleaner, better defined red spots in subsequent assays were obtained if the solution was frozen in a dry-ice bath after the 40-hour incubation and then thawed at room temperature. Either way, the solution was next centrifuged at 14,000 rpm in an Eppendorf Centrifuge 5414 for about 15 minutes to give a very pale pink supernatant containing most of the oligonucleotide (as indicated by the absorbance at 260 nm) along with 7-10% of the colloidal gold (as indicated by the absorbance at 520 nm), and a compact, dark, gelatinous residue at the bottom of the tube. The supernatant was removed, and the residue was resuspended in about 200 µL of buffer (10 mM phosphate, 0.1 M NaCl) and recentrifuged. After removal of the supernatant solution, the residue was taken up in 1.0 mL of buffer (10 mM phosphate, 0.1 M NaCl) and 10 µL of a 1% aqueous solution of NaN_3. Dissolution was assisted by drawing the solution into, and expelling it from, a pipette several times. The resulting red master solution was stable (*i.e.*, remained red and did not aggregate) on standing for months at room temperature, on spotting on silica thin-layer chromatography (TLC) plates (see Example 4), and on addition to 2 M NaCl, 10 mM $MgCl_2$, or solutions containing high concentrations of salmon sperm DNA.

Example 4: Acceleration Of Hybridization Of Nanoparticle-Oligonucleotide Conjugates

The oligonucleotide-gold colloid conjugates I and II illustrated in Figure 11 were prepared as described in Example 3. The hybridization of these two conjugates was extremely slow. In particular, mixing samples of

conjugates I and II in aqueous 0.1 M NaCl or in 10 mM $MgCl_2$ plus 0.1 M NaCl and allowing the mixture to stand at room temperature for a day produced little or no color change.

Two ways were found to improve hybridization. First, faster results were obtained by freezing the mixture of conjugates I and II (each 15 nM contained in a solution of 0.1 M NaCl) in a dry ice-isopropyl alcohol bath for 5 minutes and then thawing the mixture at room temperature. The thawed solution exhibited a bluish color. When 1 µL of the solution was spotted on a standard C-18 TLC silica plate (Alltech Associates), a strong blue color was seen immediately. The hybridization and consequent color change caused by the freeze-thawing procedure were reversible. On heating the hybridized solution to 80°C, the solution turned red and produced a pink spot on a TLC plate. Subsequent freezing and thawing returned the system to the (blue) hybridized state (both solution and spot on a C-18 TLC plate). In a similar experiment in which the solution was not refrozen, the spot obtained on the C-18 TLC plate was pink.

A second way to obtain faster results is to warm the conjugates and target. For instance, in another experiment, oligonucleotide-gold colloid conjugates and an oligonucleotide target sequence in a 0.1 M NaCl solution were warmed rapidly to 65°C and allowed to cool to room temperature over a period of 20 minutes. On spotting on a C-18 silica plate and drying, a blue spot indicative of hybridization was obtained. In contrast, incubation of the conjugates and target at room temperature for an hour in 0.1 M NaCl solution did not produce a blue color indicative of hybridization. Hybridization is more rapid in 0.3 M NaCl.

Example 5: Assays Using Nanoparticle-Oligonucleotide Conjugates

The oligonucleotide-gold colloid conjugates 1 and 2 illustrated in Figure 12 were prepared as described in Example 3, and the oligonucleotide target 3 illustrated in Figure 12 was prepared as described in Example 2. Mismatched and deletion targets 4, 5, 6, and 7 were purchased from the Northwestern University Biotechnology Facility, Chicago, IL. These oligonucleotides were synthesized on a 40 nmol scale and purified on an reverse phase C18 cartridge (OPC). Their purity was determined by performing ion exchange HPLC.

Selective hybridization was achieved by heating rapidly and then cooling rapidly to the stringent temperature. For example, hybridization was carried out in 100 µL of 0.1 M NaCl plus 5 mM $MgCl_2$ containing 15 nM of each oligonucleotide-colloid conjugate 1 and 2, and 3 nanomoles of target oligonucleotide 3, 4, 5, 6, or 7, heating to 74°C, cooling to the temperatures indicated in Table 1 below, and incubating the mixture at this temperature for 10 minutes. A 3 µL sample of each reaction mixture was then spotted on a C-18 TLC silica plate. On drying (5 minutes), a strong blue color appeared if hybridization had taken place.

The results are presented in Table 1 below. Pink spots signify a negative test (*i.e.*, that the nanoparticles were not brought together by hybridization), and blue spots signify a positive test (*i.e.*, that the nanoparticles were brought into proximity due to hybridization involving both of the oligonucleotide-colloid conjugates).

TABLE 1

REACTANTS	RESULTS (COLOR)			
	45°C	50°C	60°C	74°C
1 + 2	PINK	PINK	PINK	PINK
1 + 2 + 3 (match)	BLUE	BLUE	BLUE	BLUE
1 + 2 + 4 (half complement mismatch)	PINK	PINK	PINK	PINK
1 + 2 + 5 (-6 bp)	BLUE	PINK	PINK	PINK
1 + 2 + 6 (1 bp mismatch)	BLUE	BLUE	PINK	PINK
1 + 2 + 7 (2 bp mismatch)	PINK	PINK	PINK	PINK

As can be seen in Table 1, hybridization at 60°C gave a blue spot only for the fully-matched target 3. Hybridization at 50°C yielded blue spots with both targets 3 and 6. Hybridization at 45°C gave blue spots with targets 3, 5 and 6.

In a related series, a target containing a single mismatch T nucleotide was found to give a positive test at 58°C (blue color) and a negative test (red color) at 64°C with conjugates 1 and 2. Under the same conditions, the fully-matched target (3) gave a positive test at both temperatures, showing that the test can discriminate between a target that is fully matched and one containing a single mismatched base.

Similar results were achieved using a different hybridization method. In particular, selective

hybridization was achieved by freezing, thawing and then warming rapidly to the stringent temperature. For example, hybridization was carried out in 100 µL of 0.1 M NaCl containing 15 nM of each oligonucleotide-colloid conjugate 1 and 2, and 10 picomoles of target oligonucleotide 3, 4, 5, 6, or 7, freezing in a dry ice-isopropyl alcohol bath for 5 minutes, thawing at room temperature, then warming rapidly to the temperatures indicated in Table 2 below, and incubating the mixture at this temperature for 10 minutes. A 3 µL sample of each reaction mixture was then spotted on a C-18 TLC silica plate. The results are presented in Table 2.

Table 2

Reactants (probes) + target	Results (color)				
	RT	35°C	40°C	54°C	64°C
(1 + 2) + 3	blue	blue	blue	blue	pink
(1 + 2)	pink	pink	pink	pink	pink
(1 + 2) + 4	pink	pink	pink	pink	pink
(1 + 2) + 5	blue	blue	pink	pink	pink
(1 + 2) + 6	blue	blue	blue	pink	pink
(1 + 2) + 7	blue	pink	pink	pink	pink

An important feature of these systems was that the color change associated with the temperature change was very sharp, occurring over a temperature range of about 1°C. This indicates high cooperativity in the melting and association processes involving the colloid conjugates and enables one to easily discriminate between oligonucleotide targets containing a fully-matched sequence and a single basepair mismatch.

The high degree of discrimination may be attributed to two features. The first is the alignment of two

relatively short probe oligonucleotide segments (15 nucleotides) on the target is required for a positive signal. A mismatch in either segment is more destabilizing than a mismatch in a longer probe (*e.g.*, an oligonucleotide 30 bases long) in a comparable two-component detection system. Second, the signal at 260 nm, obtained on hybridization of the target oligonucleotides with the nanoparticle conjugates in solution, is nanoparticle-based, not DNA-based. It depends on dissociation of an assembly of nanoparticles organized in a polymeric network by multiple oligonucleotide duplexes. This results in a narrowing of the temperature range that is observed for aggregate dissociation, as compared with standard DNA thermal denaturation. In short, some duplexes in the crosslinked aggregates can dissociate without dispersing the nanoparticles into solution. Therefore, the temperature range for aggregate melting is very narrow (4°C) as compared with the temperature range associated with melting the comparable system without nanoparticles (12°C). Even more striking and advantageous for this detection approach is the temperature range for the colorimetric response (<1°C) observe on the C18 silica plates. In principle, this three-component nanoparticle based strategy will be more selective than any two-component detection system based on a single-strand probe hybridizing with target nucleic acid.

A master solution containing 1 nmol of target 3 was prepared in 100 µl of hybridization buffer (0.3 M NaCl, 10 mM phosphate, pH 7). One µl of this solution corresponds to 10 picomole of target oligonucleotide. Serial dilutions were performed by taking an aliquot of the master solution and diluting it to the desired concentration with hybridization buffer. Table 3 shows the sensitivity obtained using 3 µl of a mixutre of

probes 1 and 2 with different amounts of target 3. After performing the hybridization using freeze-thaw conditions, 3 µl aliquots of these solutions were spotted onto C-18 TLC plates to determine color. In Table 3 below, pink signifies a negative test, and blue signifies a positive test.

Table 3

Amount of Target	Results
1 picomole	blue (positive)
200 femtomole	blue (positive)
100 femtomole	blue (positive)
20 femtomole	blue (positive)
10 femtomole	purplish (ambiguous)

This experiment indicates that 10 femtomoles is the lower limit of detection for this particular system.

Example 6: Assays Using Nanoparticle-Oligonucleotide Conjugates

DNA modified nanoparticles were adsorbed onto modified transparent substrates as shown in Figure 13B, panels 1-6. This method involved the linking of DNA modified nanoparticles to nanoparticles that were attached to a glass substrate, using DNA hybridization interactions.

Glass microscope slides were purchased from Fisher scientific. Slides were cut into approximately 5 x 15 mm pieces, using a diamond tipped scribing pen. Slides were cleaned by soaking for 20 minutes in a solution of 4:1 H_2SO_4:H_2O_2 at 50°C. Slides were then rinsed with copious amounts of water, then ethanol, and dried under a stream of dry nitrogen. To functionalize the slide surface with a thiol terminated silane, the slides were soaked in a degassed ethanolic 1% (by volume)

mercaptopropyltrimethoxysilane solution for 12 hours. The slides were removed from the ethanol solutions and rinsed with ethanol, then water. Nanoparticles were adsorbed onto the thiol terminated surface of the slides by soaking in solutions containing the 13 nm diameter gold nanoparticles (preparation described in Example 1). After 12 hours in the colloidal solutions, the slides were removed and rinsed with water. The resulting slides have a pink appearance due to the adsorbed nanoparticles and exhibit similar UV-vis absorbance profiles (surface plasmon absorbance peak at 520 nm) as the aqueous gold nanoparticle colloidal solutions. See Figure 14A.

DNA was attached to the nanoparticle modified surface by soaking the glass slides in 0.2 OD (1.7 μM) solution containing freshly purified 3' thiol oligonucleotide (3' thiol ATGCTCAACTCT [SEQ ID NO:33]) (synthesized as described in Examples 1 and 3). After 12 hours of soaking time, the slides were removed and rinsed with water.

To demonstrate the ability of an analyte DNA strand to bind nanoparticles to the modified substrate, a linking oligonucleotide was prepared. The linking oligonucleotide (prepared as described in Example 2) was 24 bp long (5' TACGAGTTGAGAATCCTGAATGCG [SEQ ID NO:34]) with a sequence containing a 12 bp end that was complementary to the DNA already adsorbed onto the substrate surface (SEQ ID NO:33). The substrate was then soaked in a hybridization buffer (0.5 M NaCl, 10 mM phosphate buffer pH 7) solution containing the linking oligonucleotide (0.4 OD, 1.7 μM) for 12 hours. After removal and rinsing with similar buffer, the substrate was soaked in a solution containing 13 nm diameter gold nanoparticles which had been modified with an oligonucleotide (TAGGACTTACGC 5' thiol [SEQ ID NO:35]) (prepared as described in Example 3) that is

complementary to the unhybridized portion of the linking oligonucleotide attached to the substrate. After 12 hours of soaking, the substrate was removed and rinsed with the hybridization buffer. The substrate color had darkened to a purple color and the UV-vis absorbance at 520 nm approximately doubled (Figure 14A).

To verify that the oligonucleotide modified gold nanoparticles were attached to the oligonucleotide/ nanoparticle modified surface through DNA hybridization interactions with the linking oligonucleotide, a melting curve was performed. For the melting experiment, the substrate was placed in a cuvette containing 1 mL of hybridization buffer and the same apparatus used in Example 2, part B, was used. The absorbance signal due to the nanoparticles (520 nm) was monitored as the temperature of the substrate was increased at a rate of 0.5°C per minute. The nanoparticle signal dramatically dropped when the temperature passed 60°C. See Figure 14B. A first derivative of the signal showed a melting temperature of 62°C, which corresponds with the temperature seen for the three DNA sequences hybridized in solution without nanoparticles. See Figure 14B.

Example 7: Assays Using Nanoparticle-Oligonucleotide Conjugates

The detection system illustrated in Figure 15 was designed so that the two probes 1 and 2 align in a tail-to-tail fashion onto a complementary target 4 (see Figure 15). This differs from the system described in Example 5 where the two probes align contiguously on the target strand (see Figure 12).

The oligonucleotide-gold nanoparticle conjugates 1 and 2 illustrated in Figure 15 were prepared as described in Example 3, except that the nanoparticles were redispersed in hybridization buffer (0.3 M NaCl, 10 mM

phosphate, pH 7). The final nanoparticle-oligonucleotide conjugate concentration was estimated to be 13 nM by measuring the reduction in intensity of the surface plasmon band at 522 nm which gives rise to the red color of the nanoparticles. The oligonucleotide targets illustrated in Figure 15 were purchased from the Northwestern University Biotechnology Facility, Evanston, IL.

When 150 µL of hybridization buffer containing 13 nM oligonucleotide-nanoparticle conjugates 1 and 2 was mixed with 60 picomoles (6 µL) of target 4, the solution color immediately changed from red to purple. This color change occurs as a result of the formation of large oligonucleotide-linked polymeric networks of gold nanoparticles, which leads to a red shift in the surface plasmon resonance of the nanoparticles. When the solution was allowed to stand for over 2 hours, precipitation of large macroscopic aggregates was observed. A 'melting analysis' of the solution with the suspended aggregates was performed. To perform the 'melting analysis', the solution was diluted to 1 ml with hybridization buffer, and the optical signature of the aggregates at 260 nm was recorded at one minute intervals as the temperature was increased from 25°C to 75°C, with a holding time of 1 minute/degree. Consistent with characterization of the aggregate as an oligonucleotide-nanoparticle polymer, a characteristic sharp transition (full width at half maximum, $FW_{1/2}$ of the first derivative = 3.5°C) was observed with a "melting temperature" (T_m) of 53.5°C. This compares well with the T_m associated with the broader transition observed for oligonucleotides without nanoparticles (T_m = 54°C, $FW_{1/2}$ = ~13.5°C). The 'melting analysis' of the oligonucleotide solution without nanoparticles was performed under similar conditions as the analysis with nanoparticles, except

that the temperature was increased from 10-80 °C. Also, the solution was 1.04 μM in each oligonucleotide component.

To test the selectivity of the system, the T_m for the aggregate formed from the perfect complement 4 of probes 1 and 2 was compared with the T_m's for aggregates formed from targets that contained one base mismatches, deletions, or insertions (Figure 15). Significantly, all of the gold nanoparticle-oligonucleotide aggregates that contained imperfect targets exhibited significant, measurable destabilization when compared to the aggregates formed from the perfect complement, as evidenced by T_m values for the various aggregates (see Figure 15). The solutions containing the imperfect targets could easily be distinguished from the solution containing the perfect complement by their color when placed in a water bath held at 52.5°C. This temperature is above the T_m of the mismatched polynucleotides, so only the solution with the perfect target exhibited a purple color at this temperature. A 'melting analysis' was also performed on the probe solution which contained the half-complementary target. Only a minute increase in absorbance at 260 nm was observed.

Next, 2 μL (20 picomoles) of each of the oligonucleotide targets (Figure 15) were added to a solution containing 50 μL of each probe (13 nM) in hybridization buffer. After standing for 15 minutes at room temperature, the solutions were transferred to a temperature-controlled water bath and incubated at the temperatures indicated in Table 4 below for five minutes. A 3 μl sample of each reaction mixture was then spotted on a C-18 silica plate. Two control experiments were performed to demonstrate that the alignment of both probes onto the target is necessary to trigger

aggregation and, therefore, a color change. The first control experiment consisted of both probes 1 and 2 without target present. The second control experiment consisted of both probes 1 and 2 with a target 3 that is complementary to only one of the probe sequences (Figure 15). The results are presented in Table 4 below. Pink spots signify a negative test, and blue spots signify a positive test.

Notably, the colorimetric transition that can be detected by the naked eye occurs over less than 1°C, thereby allowing one to easily distinguish the perfect target 4 from the targets with mismatches (5 and 6), an end deletion (7), and a one base insertion at the point in the target where the two oligonucleotide probes meet (8) (see Table 4). Note that the colorimetric transition T_c is close in temperature, but not identical, to T_m. In both controls, there were no signs of particle aggregation or instability in the solutions, as evidenced by the pinkish red color which was observed at all temperatures, and they showed negative spots (pink) in the plate test at all temperatures (Table 4).

The observation that the one base insertion target 8 can be differentiated from the fully complementary target 4 is truly remarkable given the complete complementarity of the insertion strand with the two probe sequences. The destabilization of the aggregate formed from 8 and the nanoparticle probes appears to be due to the use of two short probes and the loss of base stacking between the two thymidine bases where the probe tails meet when hybridized to the fully complementary target. A similar effect was observed when a target containing a three base pair insertion (CCC) was hybridized to the probes under comparable conditions, (T_m = 51°C). In the system described above in Example 5, targets with base insertions could not be distinguished from the fully

complementary target. Therefore, the system described in this example is very favorable in terms of selectivity. This system also exhibited the same sensitivity as the system described in Example 5, which is approximately 10 femtomoles without amplification techniques.

The results indicate that any one base mismatch along the target strand can be detected, along with any insertions into the target strand. Importantly, the temperature range over which a color change can be detected is extremely sharp, and the change occurs over a very narrow temperature range. This sharp transition indicates that there is a large degree of cooperativity in the melting process involving the large network of colloids which are linked by the target oligonucleotide strands. This leads to the remarkable selectivity as shown by the data.

Table 4

Reactants (probes) + target	Results (color)					
	RT	47.6°C	50.5°C	51.4°C	52.7°C	54.5°C
(1 + 2)	pink	pink	pink	pink	pink	pink
(1 + 2) + 3	pink	pink	pink	pink	pink	pink
(1 + 2) + 4	blue	blue	blue	blue	blue	pink
(1 + 2) + 5	blue	blue	blue	pink	pink	pink
(1 + 2) + 6	blue	pink	pink	pink	pink	pink
(1 + 2) + 7	blue	blue	blue	blue	pink	pink
(1 + 2) + 8	blue	blue	pink	pink	pink	pink

Example 8: Assays Using Nanoparticle-Oligonucleotide Conjugates

A set of experiments were performed involving hybridization with 'filler' duplex oligonucleotides. Nanoparticle-oligonucleotide conjugates 1 and 2 illustrated in Figure 16 were incubated with targets of different lengths (24, 48 and 72 bases in length) and complementary filler oligonucleotides, as illustrated in Figure 16. Otherwise, the conditions were as described in Example 7. Also, the oligonucleotides and nanoparticle-oligonucleotide conjugates were prepared as described in Example 7.

As expected, the different reaction solutions had markedly different optical properties after hybridization due to the distance-dependent optical properties of the gold nanoparticles. See Table 5 below. However, when these solutions were spotted onto a C-18 TLC plate, a blue color developed upon drying at room temperature or 80°C, regardless of the length of the target oligonucleotide and the distance between the gold nanoparticles. See Table 5. This probably occurs because the solid support enhances aggregation of the hybridized oligonucleotide-nanoparticle conjugates. This demonstrates that by spotting solutions onto the TLC plate, the distance between the gold nanoparticles can be substantial (at least 72 bases), and colorimetric detection is still possible.

TABLE 5

TARGET LENGTH	RESULTS (COLOR)	
	SOLUTION	TLC PLATE
24 BASES	BLUE	BLUE
48 BASES	PINK	BLUE
72 BASES	PINK	BLUE
PROBES 1 + 2 ONLY	PINK	PINK

The color changes observed in this and other examples occur when the distance between the gold nanoparticles (the interparticle distance) is approximately the same or less than the diameter of the nanoparticle. Thus, the size of the nanoparticles, the size of the oligonucleotides attached to them, and the spacing of the nanoparticles when they are hybridized to the target nucleic acid affect whether a color change will be observable when the oligonucleotide-nanoparticle conjugates hybridize with the nucleic acid targets to form aggregates. For instance, gold nanoparticles with diameters of 13 nm will produce a color change when aggregated using oligonucleotides attached to the nanoparticles designed to hybridize with target sequences 10-35 nucleotides in length. The spacing of the nanoparticles when they are hybridized to the target nucleic acid adequate to give a color change will vary with the extent of aggregation, as the results demonstrate. The results also indicate that the solid surface enhances further aggregation of already-aggregated samples, bringing the gold nanoparticles closer together.

The color change observed with gold nanoparticles is attributable to a shift and broadening of the surface

plasmon resonance of the gold. This color change is unlikely for gold nanoparticles less than about 4 nm in diameter because the lengths of the oligonucleotides necessary for specific detection of nucleic acid would exceed the nanoparticle diameter.

Example 9: Assays Using Nanoparticle-Oligonucleotide Conjugates

Five microliters of each probe 1 and 2 (Figure 12) were combined to a final concentration of 0.1 M NaCl with buffer (10 mM phosphate, pH 7), and 1 microliter of human urine was added to the solution. When this solution was frozen, thawed, and then spotted on a C-18 TLC plate, a blue color did not develop. To a similar solution containing 12.5 microliters of each probe and 2.5 microliters of human urine, 0.25 microliters (10 picomoles) of target 3 (Figure 12) was added. The solution was frozen, thawed and then spotted onto a C-18 TLC plate, and a blue spot was obtained.

Similar experiments were performed in the presence of human saliva. A solution containing 12.5 microliters of each probe 1 and 2 and 0.25 microliters of target 3 was heated to 70°C. After cooling to room temperature, 2.5 microliters of a saliva solution (human saliva diluted 1:10 with water) was added. After the resultant solution was frozen, thawed and then spotted onto a C-18 TLC plate, a blue spot was obtained, indicating hybridization of the probes with the target. In control experiments with no target added, blue spots were not observed.

Example 10: Assays Using Nanoparticle-Oligonucleotide Conjugates

An assay was performed as illustrated in Figure 13A. First, glass microscope slides, purchased from Fisher scientific, were cut into approximately 5 x 15 mm pieces,

using a diamond tipped scribing pen. Slides were cleaned by soaking for 20 minutes in a solution of 4:1 H_2SO_4:H_2O_2 at 50°C. Slides were then rinsed with copious amounts of water, then ethanol, and dried under a stream of dry nitrogen. Thiol-modified DNA was adsorbed onto the slides using a modified procedure reported in the literature (Chrisey et al., *Nucleic Acids Res.*, **24**, 3031-3039 (1996) and Chrisey et al., *Nucleic Acids Res.*, **24**, 3040-3047 (1996)). First, the slides were soaked in a 1% solution of trimethoxysilylpropyldiethyltriamine (DETA, purchased from United Chemical Technologies, Bristol, PA) in 1 mM acetic acid in Nanopure water for 20 minutes at room temperature. The slides were rinsed with water, then ethanol. After drying with a dry nitrogen stream, the slides were baked at 120°C for 5 minutes using a temperature-controlled heating block. The slides were allowed to cool, then were soaked in a 1 mM succinimidyl 4-(malemidophenyl)-butyrate (SMPB, purchased from Sigma Chemicals) solution in 80:20 methanol:dimethoxysulfoxide for 2 hours at room temperature. After removal from the SMPB solution and rinsing with ethanol, amine sites that were not coupled to the SMPB crosslinker were capped as follows. First, the slides were soaked for 5 minutes in a 8:1 THF:pyridine solution containing 10% 1-methyl imidazole. Then the slides were soaked in 9:1 THF:acetic anhydride solution for five minutes. These capping solutions were purchased from Glen Research, Sterling, VA. The slides were rinsed with THF, then ethanol, and finally water.

DNA was attached to the surfaces by soaking the modified glass slides in a 0.2 OD (1.7 μM) solution containing freshly purified oligonucleotide (3' thiol ATGCTCAACTCT [SEQ ID NO:33]). After 12 hours of soaking time, the slides were removed and rinsed with water.

To demonstrate the ability of an analyte DNA strand to bind nanoparticles to the modified substrate, a linking oligonucleotide was prepared. The linking oligonucleotide was 24 bp long (5' TACGAGTTGA GAATCCTGAATGCG [SEQ ID NO:34]) with a sequence containing a 12 bp end that was complementary to the DNA already adsorbed onto the substrate surface. The substrate was then soaked in a hybridization buffer (0.5 M NaCl, 10 mM phosphate buffer pH 7) solution containing the linking oligonucleotide (0.4 OD, 1.7 μM) for 12 hours. After removal and rinsing with similar buffer, the substrate was soaked in a solution containing 13 nm diameter gold nanoparticles which had been modified with an oligonucleotide (TAGGACTTACGC 5' thiol [SEQ ID NO:35]) that is complementary to the unhybridized portion of the linking oligonucleotide attached to the substrate. After 12 hours of soaking, the substrate was removed and rinsed with the hybridization buffer. The glass substrate's color had changed from clear and colorless to a transparent pink color. See Figure 19A.

Additional layers of nanoparticles were added to the slides by soaking the slides in a solution of the linking oligonucleotide as described above and then soaking in a solution containing 13 nm gold nanoparticled having oligonucleotides (3' thiol ATGCTCAACTCT [SEQ ID NO:33]) attached thereto. After soaking for 12 hours, the slides were removed from the nanoparticle solution and rinsed and soaked in hybridization buffer as described above. The color of the slide had become noticeably more red. See Figure 19A. A final nanoparticle layer was added by repeating the linking oligonucleotide and nanoparticle soaking procedures using 13 nm gold nanoparticles which had been modified with an oligonucleotide (TAGGACTTACGC 5' thiol [SEQ ID NO:35]) as the final nanoparticle layer.

Again, the color darkened, and the UV-vis absorbance at 520 nm increased. See Figure 19A.

To verify that the oligonucleotide modified gold nanoparticles were attached to the oligonucleotide modified surface through DNA hybridization interactions with the linking oligonucleotide, a melting curve was performed. For the melting experiment, a slide was placed in a cuvette containing 1.5 mL of hybridization buffer, and an apparatus similar to that used in Example 2, part B, was used. The absorbance signal due to the nanoparticles (520 nm) was monitored at each degree as the temperature of the substrate was increased from 20°C to 80°C, with a hold time of 1 minute at each integral degree. The nanoparticle signal dramatically dropped when the temperature passed 52°C. See Figure 19B. A first derivative of the signal showed a melting temperature of 55°C, which corresponds with the temperature seen for the oligonucleotide-nanoparticle conjugates and linking oligonculeotides hybridized in solution. See Figure 19B.

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(2) INFORMATION FOR SEQ ID NO:1:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 20 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

AAACGACTCT AGCGCGTATA 20

(2) INFORMATION FOR SEQ ID NO:2:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 20 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

ATGGCAACTA TACGCGCTAG 20

(2) INFORMATION FOR SEQ ID NO:3:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 16 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

CCTTGAGATT TCCCTC 16

(2) INFORMATION FOR SEQ ID NO:4:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 16 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:4:

GAGGGAAATC TCAAGG 16

(2) INFORMATION FOR SEQ ID NO:5:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 18 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:5:

AACTTGCGCT AATGGCGA 18

(2) INFORMATION FOR SEQ ID NO:6:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 26 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:6:

AAGTTGCGCT TTACGGCTAA TGGCGA 26

(2) INFORMATION FOR SEQ ID NO:7:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 15 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:7:

TCTCCTTCCC TTTTC 15

(2) INFORMATION FOR SEQ ID NO:8:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 15 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:8:

GAAAAGGGAA GGAGA 15

(2) INFORMATION FOR SEQ ID NO:9:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 15 base pairs
(B) TYPE: nucleic acid

(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:9:

CTTTTCCCTT CCTCT 15

(2) INFORMATION FOR SEQ ID NO:10:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 28 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:10:

AAACGACTCT AGCGCGTATA GTTGCCAT 28

(2) INFORMATION FOR SEQ ID NO:11:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 28 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:11:

ATGGCAACTA TACGCGCTAG AGTCGTTT 28

(2) INFORMATION FOR SEQ ID NO:12:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 15 base pairs

(B) TYPE: nucleic acid

(C) STRANDEDNESS: single

(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid

(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:12:

CCTATCGACC ATGCT 15

(2) INFORMATION FOR SEQ ID NO:13:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 30 base pairs

(B) TYPE: nucleic acid

(C) STRANDEDNESS: single

(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid

(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:13:

AGCATGGTCG ATAGGAAACG ACTCTAGCGC 30

(2) INFORMATION FOR SEQ ID NO:14:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 15 base pairs

(B) TYPE: nucleic acid

(C) STRANDEDNESS: single

(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid

(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:14:

GCGCTAGAGT CGTTT 15

(2) INFORMATION FOR SEQ ID NO:15:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 30 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:15:

AGCATGGTCG ATAGGATGGC AACTATACGC 30

(2) INFORMATION FOR SEQ ID NO:16:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 24 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:16:

GTCGATAGGA AACGACTCTA GCGC 24

(2) INFORMATION FOR SEQ ID NO:17:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 30 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:17:

AGCATGGTTG ATAGGAAACG ACTCTAGCGC 30

(2) INFORMATION FOR SEQ ID NO:18:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 30 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:18:

AGCATGTTTG ATAGGAAACG ACTCTAGCGC 30

(2) INFORMATION FOR SEQ ID NO:19:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 12 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:19:

TCTCAACTCG TA 12

(2) INFORMATION FOR SEQ ID NO:20:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 12 base pairs

(B) TYPE: nucleic acid

(C) STRANDEDNESS: single

(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid

(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:20:

CGCATTCAGG AT 12

(2) INFORMATION FOR SEQ ID NO:21:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 24 base pairs

(B) TYPE: nucleic acid

(C) STRANDEDNESS: single

(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid

(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:21:

TACGAGTTGA GAGAGTGCCC ACAT 24

(2) INFORMATION FOR SEQ ID NO:22:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 24 base pairs

(B) TYPE: nucleic acid

(C) STRANDEDNESS: single

(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid

(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:22:

TACGAGTTGA GAATCCTGAA TGCG 24

(2) INFORMATION FOR SEQ ID NO:23:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 24 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:23:

TACGAGTTGA GAATCCTGAA TGCT 24

(2) INFORMATION FOR SEQ ID NO:24:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 24 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:24:

TACGAGTTGA GACTCCTGAA TGCG 24

(2) INFORMATION FOR SEQ ID NO:25:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 23 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:25:

TACGAGTTGA GAATCCTGAA TGC 23

(2) INFORMATION FOR SEQ ID NO:26:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 25 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:26:

TACGAGTTGA GACATCCTGA ATGCG 25

(2) INFORMATION FOR SEQ ID NO:27:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 24 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:27:

TACGAGTTGA GAATCCTGAA TGCG 24

(2) INFORMATION FOR SEQ ID NO:28:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 12 base pairs

(B) TYPE: nucleic acid

(C) STRANDEDNESS: single

(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid

(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:28:

CGCATTCAGG AT 12

(2) INFORMATION FOR SEQ ID NO:29:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 48 base pairs

(B) TYPE: nucleic acid

(C) STRANDEDNESS: single

(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid

(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:29:

TACGAGTTGA GACCGTTAAG ACGAGGCAAT CATGCAATCC TGAATGCG 48

(2) INFORMATION FOR SEQ ID NO:30:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 24 base pairs

(B) TYPE: nucleic acid

(C) STRANDEDNESS: single

(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid

(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:30:

TGCATGATTG CCTCGTCTTA ACGG 24

(2) INFORMATION FOR SEQ ID NO:31:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 72 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:31:

TACGAGTTGA GACCGTTAAG ACGAGGCAAT CATGCATATA TTGGACGCTT TACGGACAAC 60

ATCCTGAATG CG 72

(2) INFORMATION FOR SEQ ID NO:32:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 48 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:32:

GTTGTCCGTA AAGCGTCCAA TATATGCATG ATTGCCTCGT CTTAACGG 48

(2) INFORMATION FOR SEQ ID NO:33:
(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 12 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:33:

TCTCAACTCG TA 12

(2) INFORMATION FOR SEQ ID NO:34:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 24 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:34:

TACGAGTTGA GAATCCTGAA TGCG 24

(2) INFORMATION FOR SEQ ID NO:35:

(i) SEQUENCE CHARACTERISTICS:
(A) LENGTH: 12 base pairs
(B) TYPE: nucleic acid
(C) STRANDEDNESS: single
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: other nucleic acid
(A) DESCRIPTION: /desc = "hypothetical"

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:35:

CGCATTCAGG AT 12

WE CLAIM:

1. A method of detecting a nucleic acid having at least two portions comprising:

providing one or more types of nanoparticles having oligonucleotides attached thereto, the oligonucleotides on each of the types of nanoparticles having a sequence complementary to the sequence of one of the portions of the nucleic acid;

contacting the nucleic acid and the nanoparticles under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the nucleic acid; and

observing a detectable change brought about by hybridization of the oligonucleotides on the nanoparticles with the nucleic acid.

2. A method of detecting nucleic acid having at least two portions comprising:

contacting the nucleic acid with at least two types of nanoparticles having oligonucleotides attached thereto, the oligonucleotides on the first type of nanoparticles having a sequence complementary to a first portion of the sequence of the nucleic acid, the oligonucleotides on the second type of nanoparticles having a sequence complementary to a second portion of the sequence of the nucleic acid, the contacting taking place under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the nucleic acid; and

observing a detectable change brought about by hybridization of the oligonucleotides on the nanoparticles with the nucleic acid.

3. The method of Claim 2 wherein the contacting conditions include freezing and thawing.

4. The method of Claim 2 wherein the contacting conditions include heating.

5. The method of Claim 2 wherein the detectable change is observed on a solid surface.

6. The method of Claim 2 wherein the detectable change is a color change observable with the naked eye.

7. The method of Claim 6 wherein the color change is observed on a solid surface.

8. The method of Claim 2 wherein the nanoparticles are made of gold.

9. The method of Claim 2 wherein the nanoparticles are metallic or semiconductor nanoparticles and the oligonucleotides attached to the nanoparticles are labeled with fluorescent molecules on the ends not attached to the nanoparticles.

10. The method of Claim 2 wherein:

the nucleic acid has a third portion located between the first and second portions, and the sequences of the oligonucleotides on the nanoparticles do not include sequences complementary to this third portion of the nucleic acid; and

the nucleic acid is further contacted with a filler oligonucleotide having a sequence complementary to this third portion of the nucleic acid, the contacting taking place under conditions effective to allow

hybridization of the filler oligonucleotide with the nucleic acid.

11. The method of Claim 2 wherein the nucleic acid is viral RNA or DNA.

12. The method of Claim 2 wherein the nucleic acid is a gene associated with a disease.

13. The method of Claim 2 wherein the nucleic acid is a bacterial DNA.

14. The method of Claim 2 wherein the nucleic acid is a fungal DNA.

15. The method of Claim 2 wherein the nucleic acid is a synthetic DNA, a synthetic RNA, a structurally-modified natural or synthetic RNA, or a structurally-modified natural or synthetic DNA.

16. The method of Claim 2 wherein the nucleic acid is from a biological source.

17. The method of Claim 2 wherein the nucleic acid is a product of a polymerase chain reaction amplification.

18. The method of Claim 2 wherein the nucleic acid is a fragment obtained by cleavage of DNA with a restriction enzyme.

19. The method of Claim 2 wherein the nucleic acid is contacted with the first and second types of nanoparticles simultaneously.

20. The method of Claim 2 wherein the nucleic acid is contacted and hybridized with the oligonucleotides on the first type of nanoparticles before being contacted with the second type of nanoparticles.

21. The method of Claim 20 wherein the first type of nanoparticles is attached to a substrate.

22. A method of detecting nucleic acid having at least two portions comprising:

providing a substrate having a first type of nanoparticles attached thereto, the nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to a first portion of the sequence of the nucleic acid;

contacting the nucleic acid with the nanoparticles attached to the substrate under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the nucleic acid;

providing a second type of nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to one or more other portions of the sequence of the nucleic acid;

contacting the nucleic acid bound to the substrate with the second type of nanoparticles under conditions effective to allow hybridization of the oligonucleotides on the second type of nanoparticles with the nucleic acid; and

observing a detectable change.

23. The method of Claim 22 wherein the nanoparticles are made of gold.

24. A method of detecting nucleic acid having at least two portions comprising:

providing a substrate having a first type of nanoparticles attached thereto, the nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to a first portion of the sequence of the nucleic acid;

contacting the nucleic acid with the nanoparticles attached to the substrate under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the nucleic acid;

providing a second type of nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to one or more other portions of the sequence of the nucleic acid;

contacting the nucleic acid bound to the substrate with the second type of nanoparticles under conditions effective to allow hybridization of the oligonucleotides on the second type of nanoparticles with the nucleic acid;

providing a binding oligonucleotide having a selected sequence having at least two portions, the first portion being complementary to at least a portion of the sequence of the oligonucleotides on the second type of nanoparticles;

contacting the binding oligonucleotide with the second type of nanoparticles bound to the substrate under conditions effective to allow hybridization of the binding oligonucleotide to the oligonucleotides on the nanoparticles;

providing a third type of nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to the sequence of a second portion of the binding oligonucleotide;

contacting the third type of nanoparticles with the binding oligonucleotide bound to the substrate under conditions effective to allow hybridization of the

binding oligonucleotide to the oligonucleotides on the nanoparticles; and

observing a detectable change.

25. The method of Claim 24 wherein the substrate is transparent.

26. The method of Claim 25 wherein the detectable change is the formation of dark areas on the substrate.

27. The method of Claim 24 wherein the nanoparticles are made of gold.

28. A method of detecting nucleic acid having at least two portions comprising:

contacting the nucleic acid with a substrate having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to a first portion of the sequence of the nucleic acid, the contacting taking place under conditions effective to allow hybridization of the oligonucleotides on the substrate with the nucleic acid;

contacting the nucleic acid bound to the substrate with a first type of nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to one or more other portions of the sequence of the nucleic acid, the contacting taking place under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the nucleic acid;

contacting the first type of nanoparticles bound to the substrate with a second type of nanoparticles having oligonucleotides attached thereto, the oligonucleotides on the second type of nanoparticles having a sequence complementary to at least a portion of

the sequence of the oligonucleotides on the first type of nanoparticles, the contacting taking place under conditions effective to allow hybridization of the oligonucleotides on the first and second types of nanoparticles; and

observing a detectable change.

29. The method of Claim 28 wherein the substrate is transparent.

30. The method of Claim 29 wherein the detectable change is the formation of dark areas on the substrate.

31. The method of Claim 28 wherein the nanoparticles are made of gold.

32. A method of detecting nucleic acid having at least two portions comprising:

contacting the nucleic acid with a substrate having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to a first portion of the sequence of the nucleic acid, the contacting taking place under conditions effective to allow hybridization of the oligonucleotides on the substrate with the nucleic acid;

contacting the nucleic acid bound to the substrate with liposomes having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to a portion of the sequence of the nucleic acid, the contacting taking place under conditions effective to allow hybridization of the oligonucleotides on the liposomes with the nucleic acid;

contacting the liposomes bound to the substrate with a first type of nanoparticles having at least a first type oligonucleotides attached thereto, the first

type of oligonucleotides having a hydrophobic group attached to the end not attached to the nanoparticles, the contacting taking place under conditions effective to allow attachment of the oligonucleotides on the nanoparticles to the liposomes as a result of hydrophobic interactions; and

observing a detectable change.

33. A method of detecting nucleic acid having at least two portions comprising

contacting the nucleic acid with a substrate having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to a first portion of the sequence of the nucleic acid, the contacting taking place under conditions effective to allow hybridization of the oligonucleotides on the substrate with the nucleic acid;

contacting the nucleic acid bound to the substrate with liposomes having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to a portion of the sequence of the nucleic acid, the contacting taking place under conditions effective to allow hybridization of the oligonucleotides on the liposomes with the nucleic acid;

contacting the liposomes bound to the substrate with a first type of nanoparticles having at least a first type oligonucleotides attached thereto, the first type of oligonucleotides having a hydrophobic group attached to the end not attached to the nanoparticles, the contacting taking place under conditions effective to allow attachment of the oligonucleotides on the nanoparticles to the liposomes as a result of hydrophobic interactions;

contacting the first type of nanoparticles bound to the liposomes with a second type of nanoparticles having oligonucleotides attached thereto,

the first type of nanoparticles having a second type of oligonucleotides attached thereto which have a sequence complementary to at least a portion of the sequence of the oligonucleotides on the second type of nanoparticles,

the oligonucleotides on the second type of nanoparticles having a sequence complementary to at least a portion of the sequence of the second type of oligonucleotides on the first type of nanoparticles,

the contacting taking place under conditions effective to allow hybridization of the oligonucleotides on the first and second types of nanoparticles; and

observing a detectable change.

34. A method of detecting a nucleic acid having at least two portions comprising:

providing nanoparticles having oligonucleotides attached thereto;

providing one or more types of binding oligonucleotides, each of the binding oligonucleotides having two portions, the sequence of one portion being complementary to the sequence of one of the portions of the nucleic acid and the sequence of the other portion being complementary to the sequence of the oligonucleotides on the nanoparticles;

contacting the nanoparticles and the binding oligonucleotides under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the binding oligonucleotides;

contacting the nucleic acid and the binding oligonucleotides under conditions effective to allow

hybridization of the binding oligonucleotides with the nucleic acid; and

observing a detectable change.

35. The method of Claim 34 wherein the nanoparticles are contacted with the binding oligonucleotides prior to being contacted with the nucleic acid.

36. A method of detecting nucleic acid having at least two portions comprising:

contacting the nucleic acid with at least two types of particles having oligonucleotides attached thereto,

the oligonucleotides on the first type of particles having a sequence complementary to a first portion of the sequence of the nucleic acid and being labeled with an energy donor,

the oligonucleotides on the second type of particles having a sequence complementary to a second portion of the sequence of the nucleic acid and being labeled with an energy acceptor,

the contacting taking place under conditions effective to allow hybridization of the oligonucleotides on the particles with the nucleic acid; and

observing a detectable change brought about by hybridization of the oligonucleotides on the particles with the nucleic acid.

37. The method of Claim 36 wherein the energy donor and acceptor are fluorescent molecules.

38. A kit comprising at least one container, the container holding a composition comprising at least two types of nanoparticles having oligonucleotides attached thereto, the oligonucleotides on the first type of

nanoparticles having a sequence complementary to the sequence of a first portion of a nucleic acid, the oligonucleotides on the second type of nanoparticles having a sequence complementary to the sequence of a second portion of the nucleic acid.

39. The kit of Claim 38 wherein the composition in the container further comprises a filler oligonucleotide having a sequence complementary to a third portion of the nucleic acid, the third portion being located between the first and second portions.

40. The kit of Claim 38 wherein the nanoparticles are made of gold.

41. The kit of Claim 38 further comprising a solid surface.

42. A kit comprising at least two containers,

the first container holding nanoparticles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid, and

the second container holding nanoparticles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a second portion of the nucleic acid.

43. The kit of Claim 42 comprising a third container holding oligonucleotides having a sequence complementary to a third portion of the nucleic acid, the third portion being located between the first and second portions.

44. The kit of Claim 42 wherein the nanoparticles are made of gold.

45. The kit of Claim 42 further comprising a solid surface.

46. A kit comprising at least two containers,

the first container holding nanoparticles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a binding oligonucleotide, and

the second container holding a binding oligonucleotide which has a sequence comprising at least two portions, the first portion being complementary to the sequence of the oligonucleotides on the nanoparticles and the second portion being complementary to the sequence of a portion of a nucleic acid.

47. The kit of Claim 46 which comprises additional containers, each holding an additional binding oligonucleotide, each additional binding oligonucleotide having a sequence comprising at least two portions, the first portion being complementary to the sequence of the oligonucleotides on the nanoparticles and the second portion being complementary to the sequence of another portion of the nucleic acid.

48. The kit of Claim 46 wherein the nanoparticles are made of gold.

49. The kit of Claim 46 further comprising a solid surface.

50. A kit comprising:

a container holding one type of nanoparticles having oligonucleotides attached thereto and one or more types of binding oligonucleotides, each of the types of binding oligonucleotides having a sequence comprising at least two portions, the first portion being complementary to the sequence of the oligonucleotides on the nanoparticles, whereby the binding oligonucleotides are hybridized to the oligonucleotides on the nanoparticles, and the second portion being complementary to the sequence of one or more portions of a nucleic acid.

50. A kit comprising at least one container, the container holding metallic or semiconductor nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to a portion of a nucleic acid and having fluorescent molecules attached to the ends of the oligonucleotides not attached to the nanoparticles.

51. A kit comprising:

a substrate, the substrate having attached thereto nanoparticles, the nanoparticles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid; and

a first container holding nanoparticles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a second portion of the nucleic acid.

52. The kit of Claim 51 further comprising:

a second container holding a binding oligonucleotide having a selected sequence having at least two portions, the first portion being complementary to at least a portion of the sequence of the

oligonucleotides on the nanoparticles in the first container; and

a third container holding nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to the sequence of a second portion of the binding oligonucleotide.

53. A kit comprising at least three containers:

the first container holding nanoparticles;

the second container holding a first oligonucleotide having a sequence complementary to the sequence of a first portion of a nucleic acid; and

the third container holding a second oligonucleotide having a sequence complementary to the sequence of a second portion of the nucleic acid.

54. The kit of Claim 53 further comprising a fourth container holding a third oligonucleotide having a sequence complementary to the sequence of a third portion of the nucleic acid, the third portion being located between the first and second portions.

55. The kit of Claim 53 further comprising a substrate.

56. The kit of Claim 55 further comprising:

a fourth container holding a binding oligonucleotide having a selected sequence having at least two portions, the first portion being complementary to at least a portion of the sequence of the second oligonucleotide; and

a fifth container holding an oligonucleotide having a sequence complementary to the sequence of a second portion of the binding oligonucleotide.

57. The kit of Claim 53 wherein the oligonucleotides, nanoparticles, or both bear functional groups for attachment of the oligonucleotides to the nanoparticles.

58. The kit of Claim 55 wherein the substrate, nanoparticles, or both bear functional groups for attachment of the nanoparticles to the substrate.

59. The kit of Claim 55 wherein the substrate has nanoparticles attached to it.

60. The kit of Claim 53 wherein the nanoparticles are made of gold.

61. A kit comprising:

a substrate having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid;

a first container holding nanoparticles having oligonucleotides attached thereto, some of which have a sequence complementary to the sequence of a second portion of the nucleic acid; and

a second container holding nanoparticles having oligonucleotides attached thereto which have a sequence complementary to at least a portion of the sequence of the oligonucleotides attached to the nanoparticles in the first container.

62. A kit comprising:

a substrate;

a first container holding nanoparticles;

a second container holding a first oligonucleotide having a sequence complementary to the sequence of a first portion of a nucleic acid;

a third container holding a second oligonucleotide having a sequence complementary to the sequence of a second portion of the nucleic acid; and

a fourth container holding a third oligonucleotide having a sequence complementary to at least a portion of the sequence of the second oligonucleotide.

63. The kit of Claim 62 wherein the oligonucleotides, nanoparticles, substrate or all bear functional groups for attachment of the oligonucleotides to the nanoparticles or for attachment of the oligonucleotides to the substrate.

64. The kit of Claim 62 wherein the nanoparticles are made of gold.

65. A kit comprising:

a substrate having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid;

a first container holding liposomes having oligonucleotides attached thereto which have a sequence complementary to the sequence of a second portion of the nucleic acid; and

a second container holding nanoparticles having at least a first type of oligonucleotides attached thereto, the first type of oligonucleotides having a hydrophobic group attached to the end not attached to the nanoparticles.

66. The kit of Claim 65 wherein:

the nanoparticles in the second container have a second type of oligonucleotides attached thereto, the second type of oligonucleotides having a sequence

complementary to the sequence of the oligonucleotides on a second type of nanoparticles;

and the kit further comprises:

a third container holding a second type of nanoparticles having oligonucleotides attached thereto, the oligonucleotides having a sequence complementary to at least a portion of the sequence of the second type of olignucleotides on the first type of nanoparticles.

67. A kit comprising at least two containers,

the first container holding particles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid, the oligonucleotides being labeled with an energy donor on the ends not attached to the particles,

the second container holding particles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a second portion of a nucleic acid, the oligonucleotides being labeled with an energy acceptor on the ends not attached to the particles.

68. The kit of Claim 67 wherein the energy donor and acceptor are fluorescent molecules.

69. A kit comprising at least one container, the container holding a first type of particles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid, the oligonucleotides being labeled with an energy donor on the ends not attached to the particles, and a second type of particles having oligonucleotides attached thereto which have a sequence complementary to the sequence of a second portion of a nucleic acid, the

oligonucleotides being labeled with an energy acceptor on the ends not attached to the particles.

70. The kit of Claim 69 wherein the energy donor and acceptor are fluorescent molecules.

71. A substrate having nanoparticles attached thereto.

72. The substrate of Claim 71 wherein the nanoparticles have oligonucleotides attached thereto which have a sequence complementary to the sequence of a first portion of a nucleic acid.

73. A metallic or semiconductor nanoparticle having oligonucleotides attached thereto, the oligonucleotides being labeled with fluorescent molecules at the ends not attached to the nanoparticle.

74. A method of nanofabrication comprising

providing at least one type of linking oligonucleotide having a selected sequence, the sequence of each type of linking oligonucleotide having at least two portions;

providing one or more types of nanoparticles having oligonucleotides attached thereto, the oligonucleotides on each of the types of nanoparticles having a sequence complementary to the sequence of a portion of a linking oligonucleotide; and

contacting the linking oligonucleotides and nanoparticles under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles to the linking oligonucleotides so that a desired nanomaterial or nanostructure is formed wherein

the nanoparticles are held together by oligonucleotide connectors.

75. The method of Claim 74 wherein the nanoparticles are made of gold.

76. The method of Claim 74 wherein at least two types of nanoparticles having oligonucleotides attached thereto are provided, the oligonucleotides on the first type of nanoparticles having a sequence complementary to a first portion of the sequence of a linking oligonucleotide, and the oligonucleotides on the second type of nanoparticles having a sequence complementary to a second portion of the sequence of the linking oligonucleotide.

77. The method of Claim 76 wherein the nanoparticles are made of gold.

78. A method of nanofabrication comprising:

providing at least two types of nanoparticles having oligonucleotides attached thereto,

the oligonucleotides on the first type of nanoparticles having a sequence complementary to that of the oligonucleotides on the second of the nanoparticles;

the oligonucleotides on the second type of nanoparticles having a sequence complementary to that of the oligonucleotides on the first type of nanoparticles; and

contacting the first and second types of nanoparticles under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles to each other so that a desired nanomaterial or nanostructure is formed.

79. The method of Claim 78 wherein the nanoparticles are made of gold.

80. Nanomaterials or nanostructures composed of nanoparticles having oligonucleotides attached thereto, the nanoparticles being held together by oligonucleotide connectors.

81. The nanomaterials or nanostructures of Claim 80 wherein at least some of the oligonucleotide connectors are triple-stranded.

82. The nanomaterials or nanostructures of Claim 80 wherein the nanoparticles are made of gold.

83. A composition comprising at least two types of nanoparticles having oligonucleotides attached thereto, the oligonucleotides on the first type of nanoparticles having a sequence complementary to the sequence of a first portion of a nucleic acid or a linking oligonucleotide, the oligonucleotides on the second type of nanoparticles having a sequence complementary to the sequence of a second portion of the nucleic acid or linking oligonucleotide.

84. The composition of Claim 83 wherein the nanoparticles are made of gold.

85. An assembly of containers comprising:

a first container holding nanoparticles having oligonucleotides attached thereto, and

a second container holding nanoparticles having oligonucleotides attached thereto,

the oligonucleotides attached to the nanoparticles in the first container having a sequence

complementary to that of the oligonucleotides attached to the nanoparticles in the second container,

the oligonucleotides attached to the nanoparticles in the second container having a sequence complementary to that of the oligonucleotides attached to the nanoparticles in the second container.

86. The assembly of Claim 85 wherein the nanoparticles are made of gold.

87. A nanoparticle having a plurality of different oligonucleotides attached thereto.

88. A method of separating a selected nucleic acid having at least two portions from other nucleic acids, the method comprising:

providing one or more types of nanoparticles having oligonucleotides attached thereto, the oligonucleotides on each of the types of nanoparticles having a sequence complementary to the sequence of one of the portions of the selected nucleic acid; and

contacting the nucleic acids and nanoparticles under conditions effective to allow hybridization of the oligonucleotides on the nanoparticles with the selected nucleic acid so that the nanoparticles hybridized to the selected nucleic acid aggregate and precipitate.

FIG.1

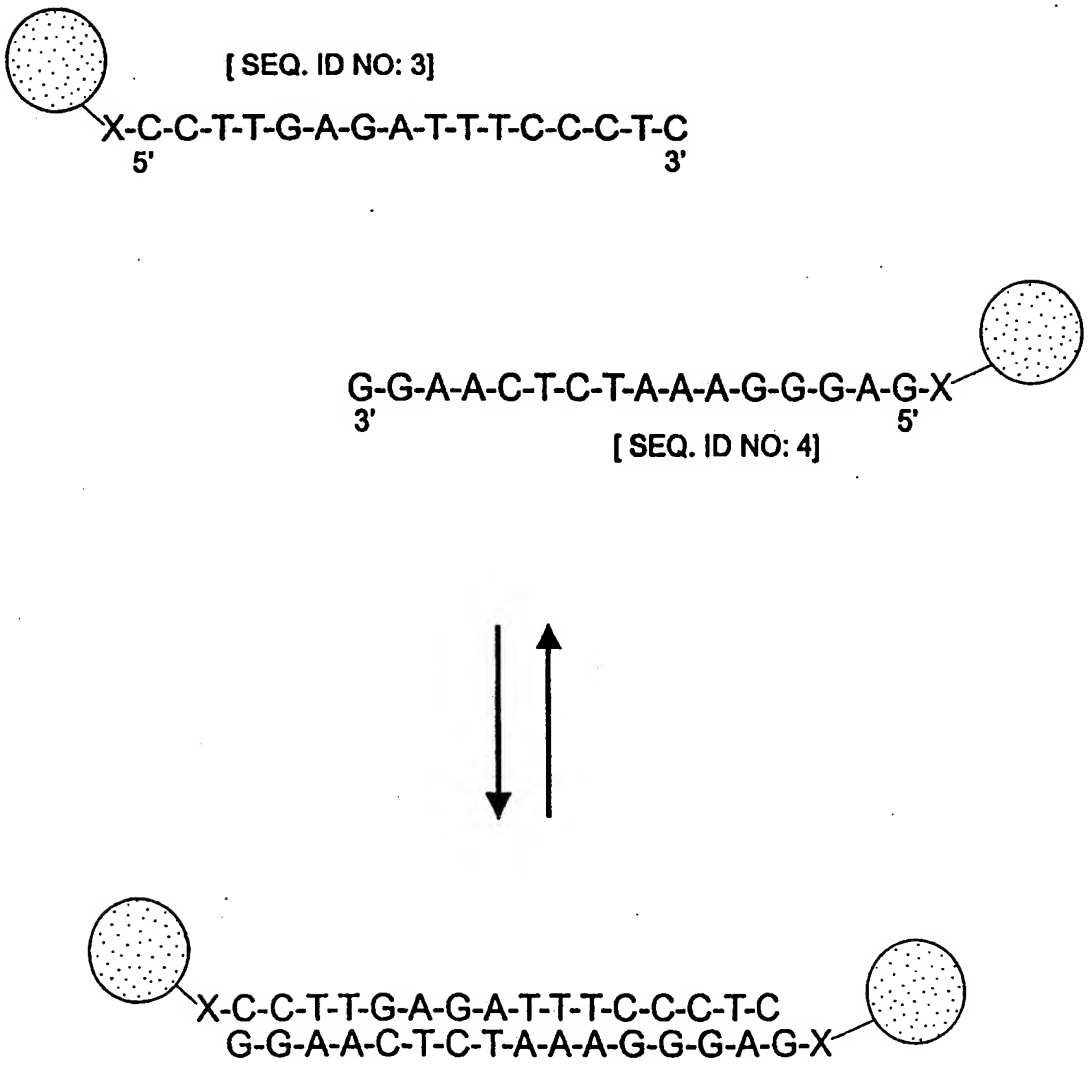

[SEQ. ID NO: 3]
X-C-C-T-T-G-A-G-A-T-T-T-C-C-C-T-C
5'
3'
G-G-A-A-C-T-C-T-A-A-A-G-G-G-A-G-X
3'
5'
[SEQ. ID NO: 4]
X-C-C-T-T-G-A-G-A-T-T-T-C-C-C-T-C
G-G-A-A-C-T-C-T-A-A-A-G-G-G-A-G-X

FIG.2

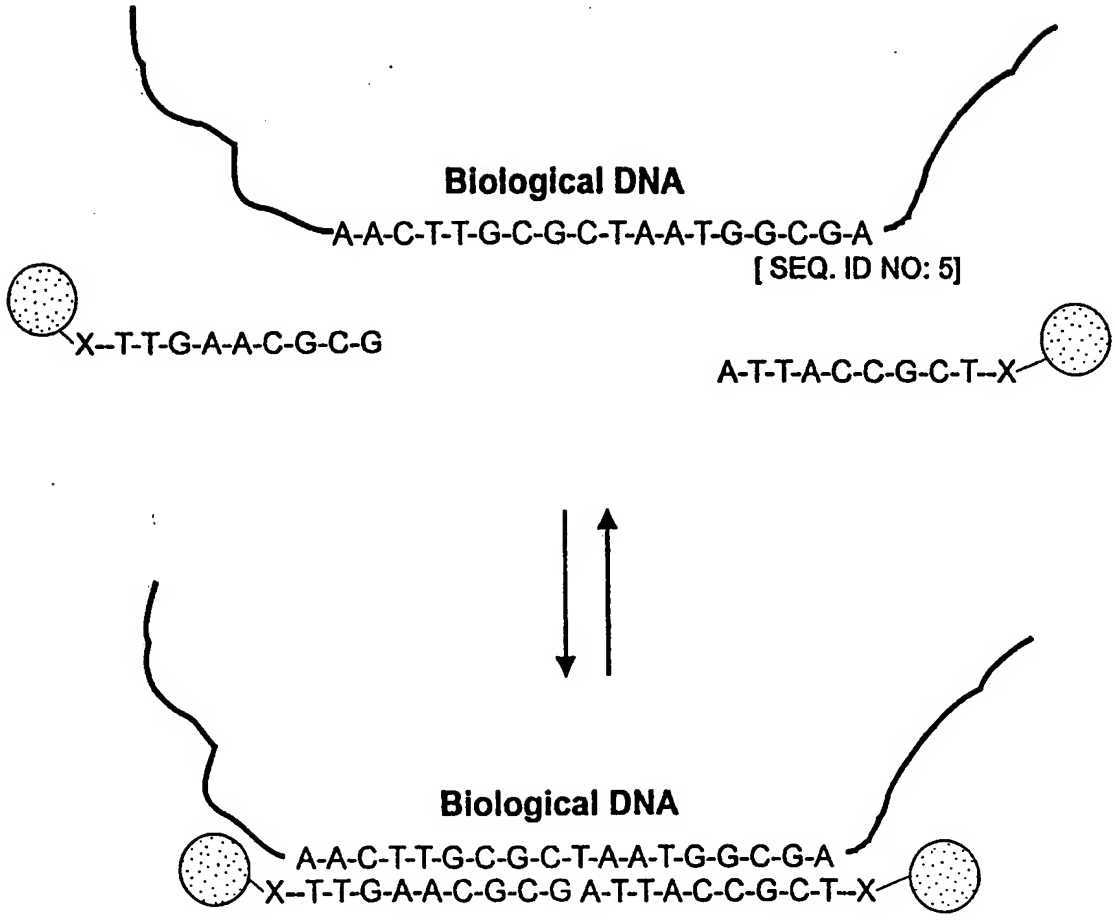

Biological DNA
A-A-C-T-T-G-C-G-C-T-A-A-T-G-G-C-G-A
[SEQ. ID NO: 5]
X--T-T-G-A-A-C-G-C-G
A-T-T-A-C-C-G-C-T--X
Biological DNA
A-A-C-T-T-G-C-G-C-T-A-A-T-G-G-C-G-A
X--T-T-G-A-A-C-G-C-G A-T-T-A-C-C-G-C-T--X

FIG.3

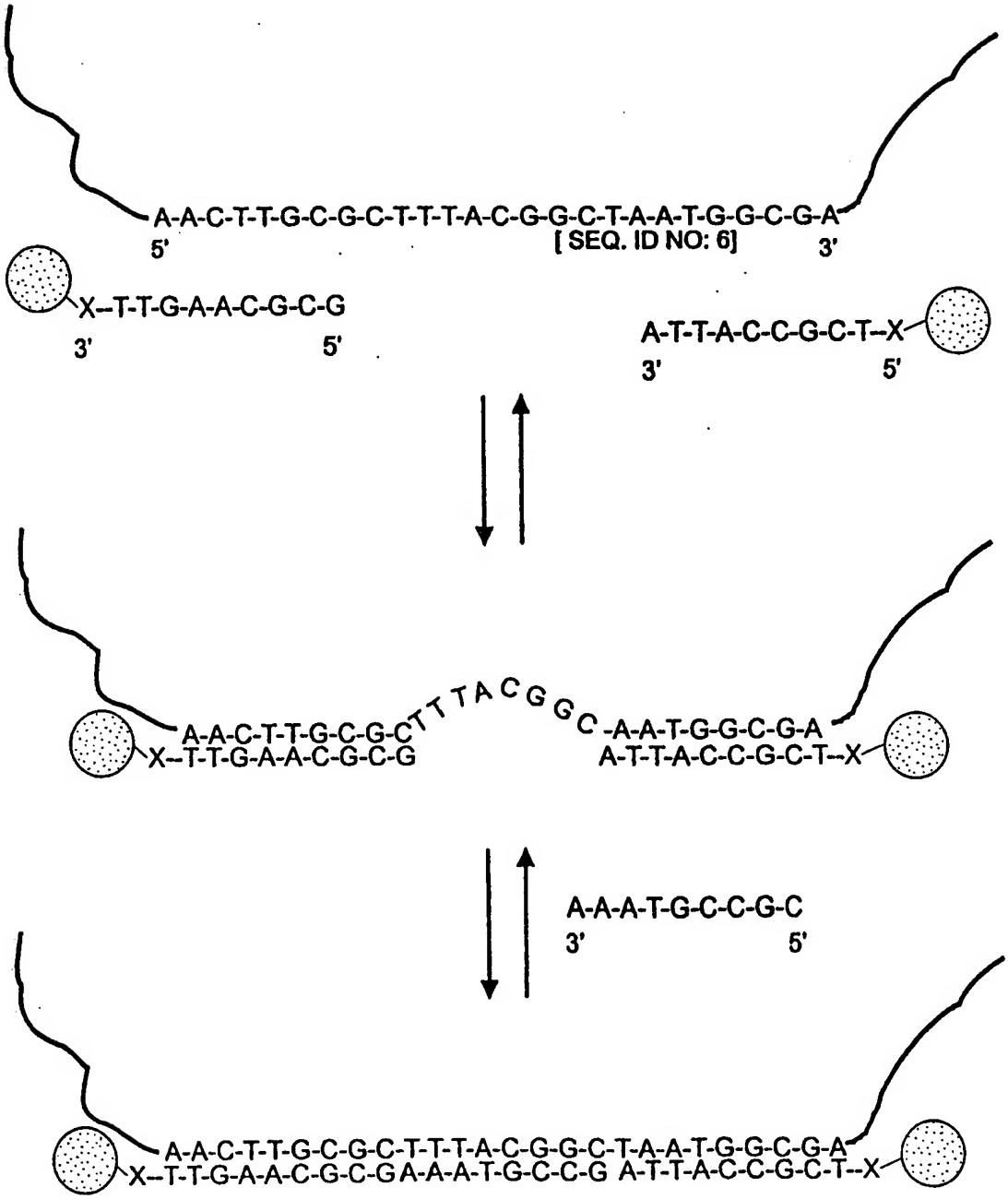

A-A-C-T-T-G-C-G-C-T-T-T-A-C-G-G-C-T-A-A-T-G-G-C-G-A
5'
[SEQ. ID NO: 6]
3'
X--T-T-G-A-A-C-G-C-G
3'
5'
A-T-T-A-C-C-G-C-T--X
3'
5'
A-A-C-T-T-G-C-G-C
T T T A C G G C
-A-A-T-G-G-C-G-A
X--T-T-G-A-A-C-G-C-G
A-T-T-A-C-C-G-C-T--X
A-A-A-T-G-C-C-G-C
3'
5'
A-A-C-T-T-G-C-G-C-T-T-T-A-C-G-G-C-T-A-A-T-G-G-C-G-A
X--T-T-G-A-A-C-G-C-G A-A-A-T-G-C-C-G A-T-T-A-C-C-G-C-T--X

FIG. 4

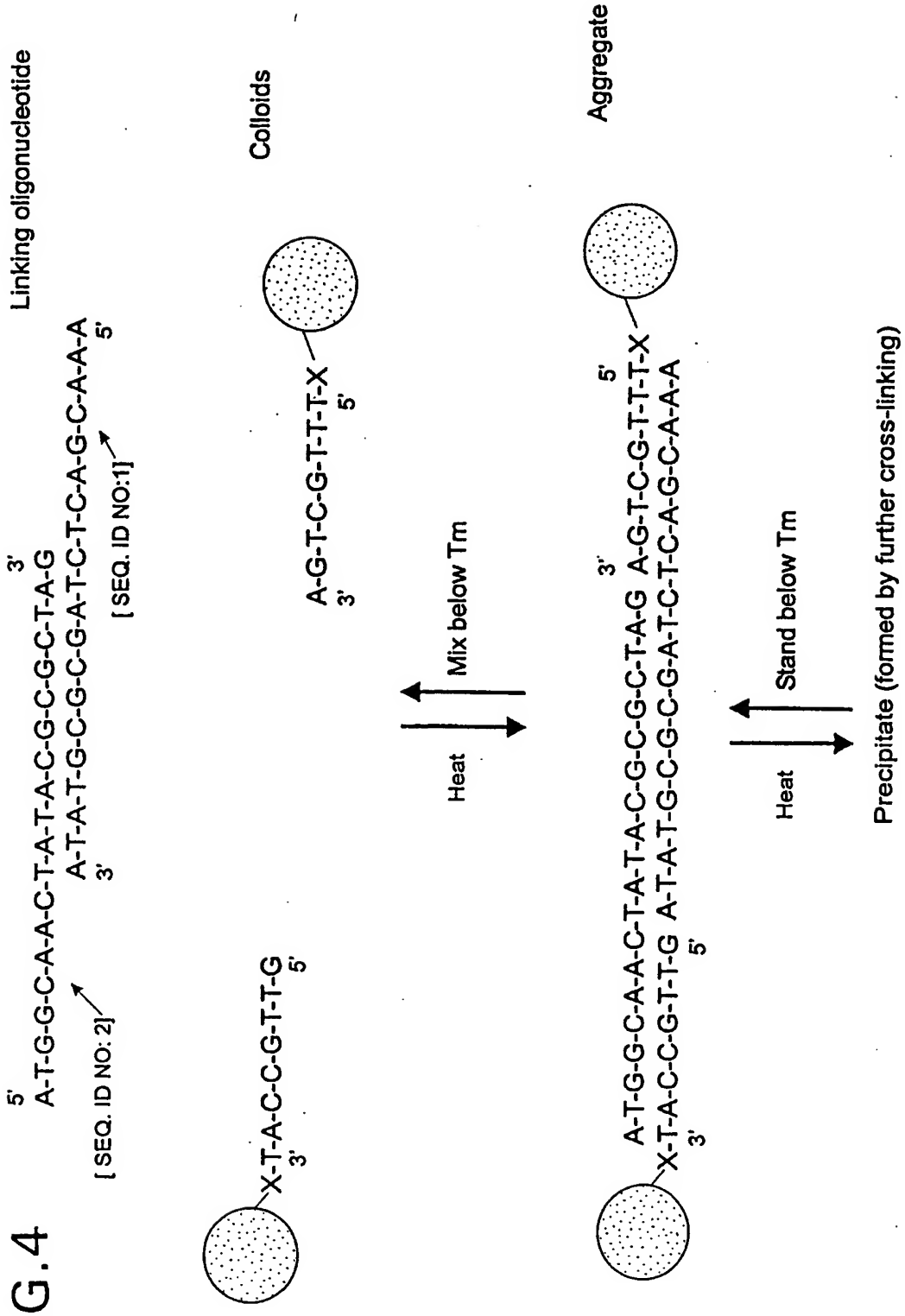

Linking oligonucleotide
5'
A-T-G-G-C-A-A-C-T-A-T-A-C-G-C-G-C-T-A-G
3'
[SEQ. ID NO: 2]
A-T-A-T-G-C-G-C-G-A-T-C-T-C-A-G-C-A-A-A
3'
5'
[SEQ. ID NO:1]
Colloids
X-T-A-C-C-G-T-T-G
3'
5'
A-G-T-C-G-T-T-T-X
3'
5'
Mix below Tm
Heat
Aggregate
A-T-G-G-C-A-A-C-T-A-T-A-C-G-C-G-C-T-A-G
3'
5'
A-G-T-C-G-T-T-T-X
X-T-A-C-C-G-T-T-G
A-T-A-T-G-C-G-C-G-A-T-C-T-C-A-G-C-A-A-A
3'
5'
Stand below Tm
Heat
Precipitate (formed by further cross-linking)

FIG.5

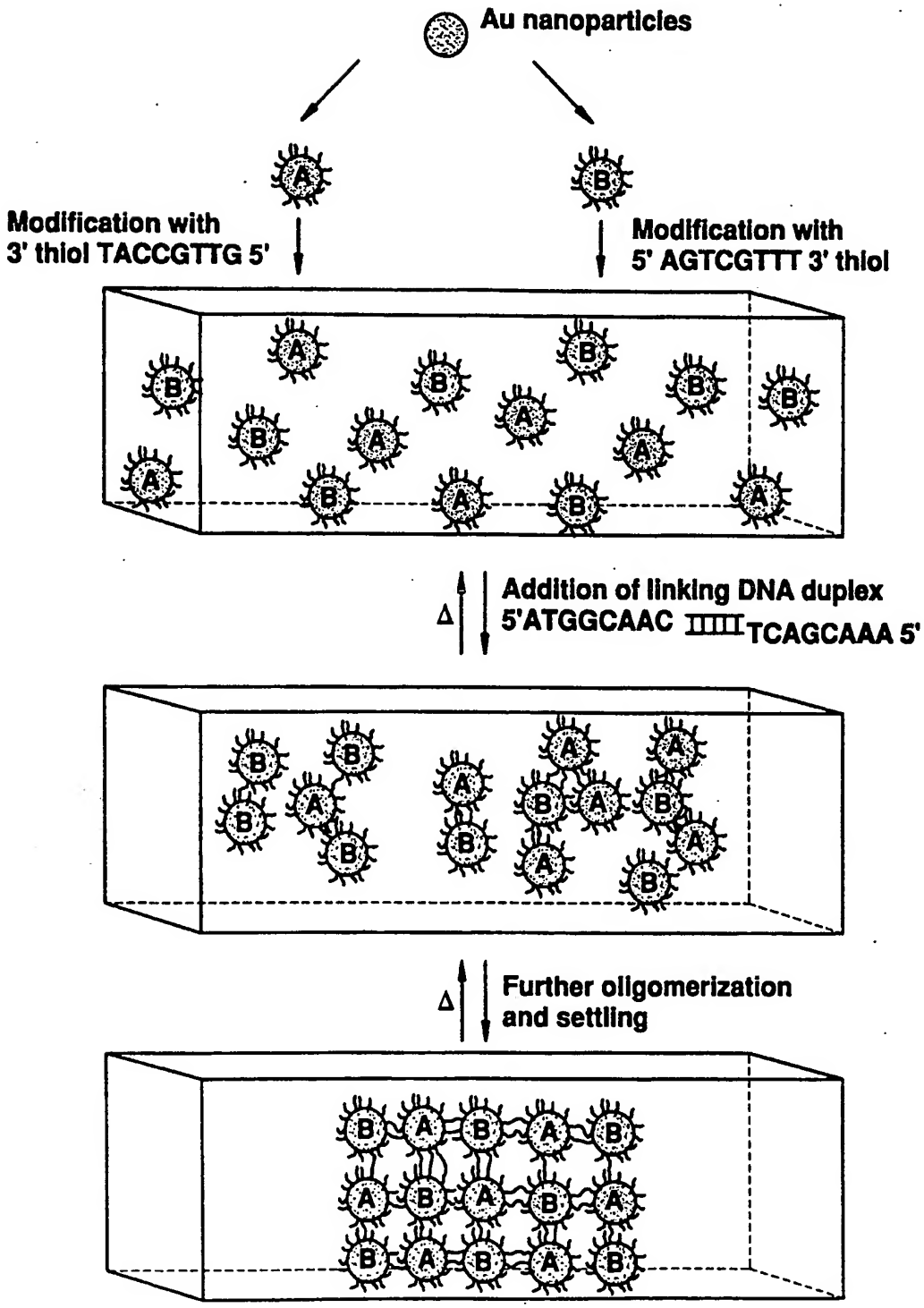

Au nanoparticles
A
B
Modification with
3' thiol TACCGTTG 5'
Modification with
5' AGTCGTTT 3' thiol
Δ
Addition of linking DNA duplex
5'ATGGCAAC IIIIITCAGCAAA 5'
Δ
Further oligomerization
and settling

FIG.6A FIG.6B FIG.6C

FIG. 7

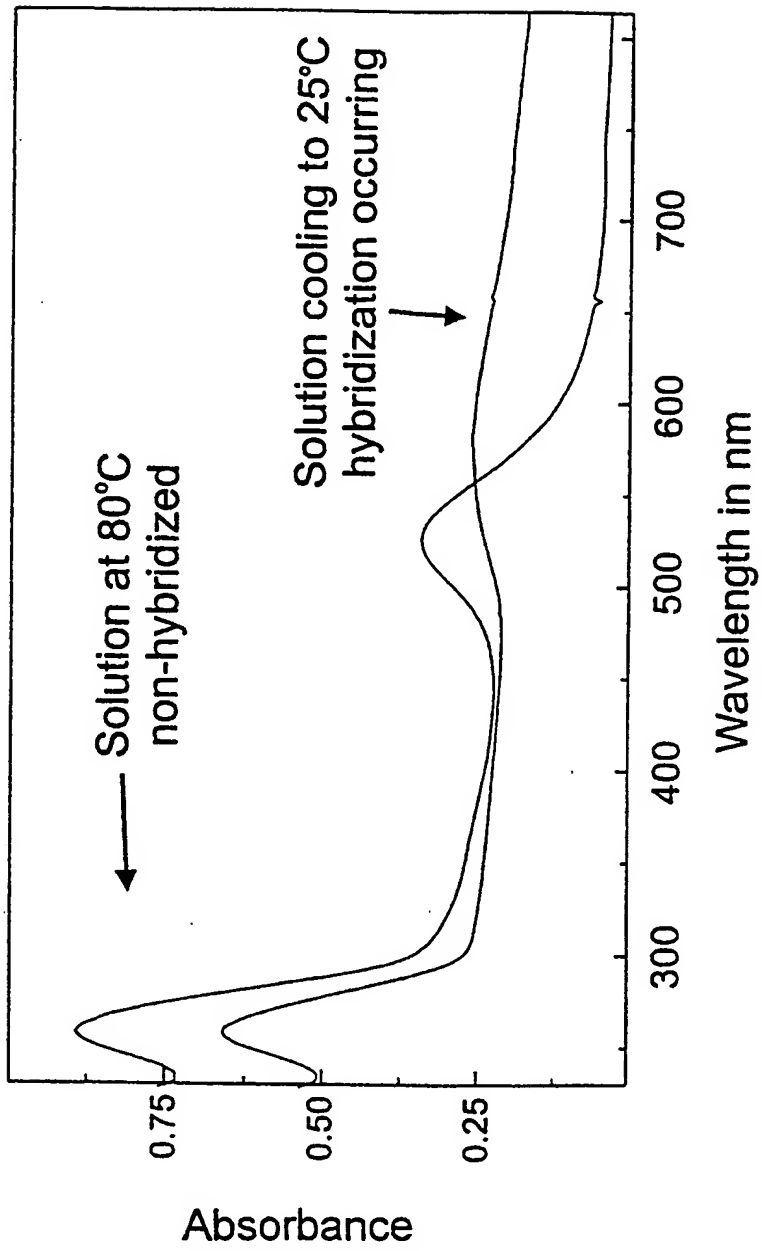

Solution at 80°C
non-hybridized
Solution cooling to 25°C
hybridization occurring
0.75
0.50
0.25
Absorbance
300
400
500
600
700
Wavelength in nm

FIG.8B

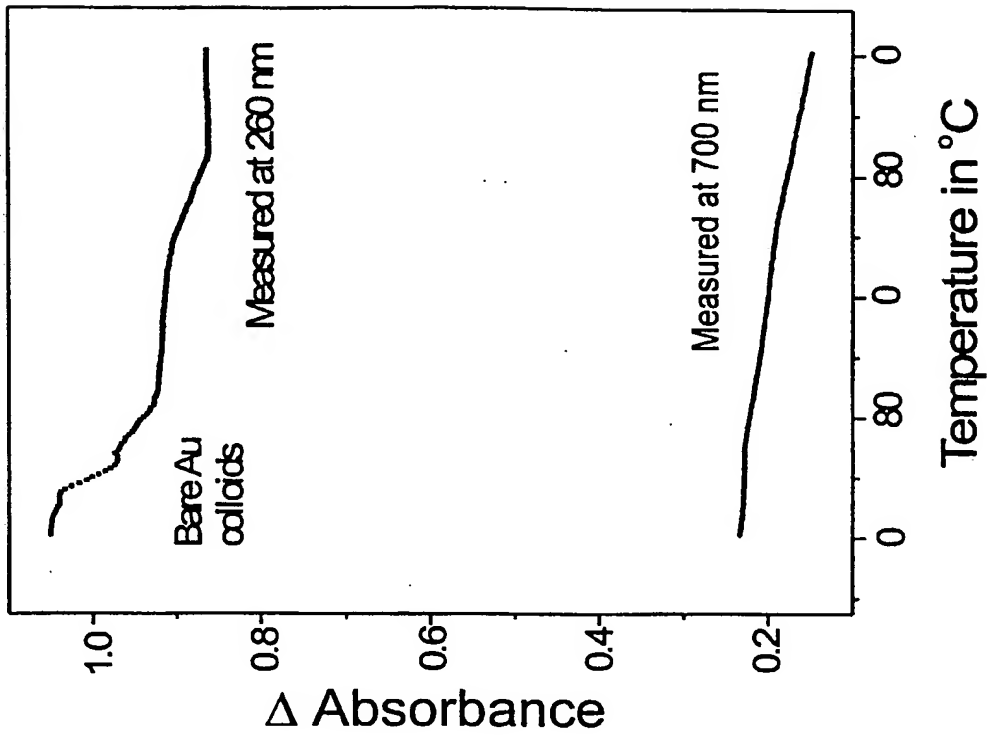
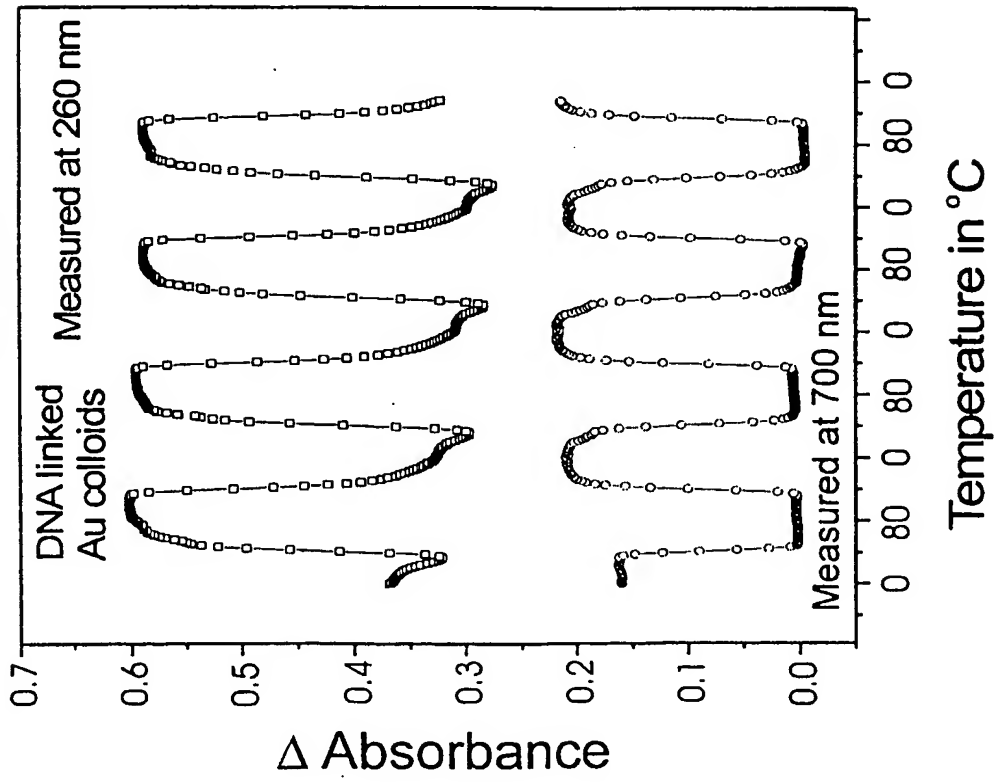

Bare Au colloids
Measured at 260 nm
Measured at 700 nm
1.0
0.8
0.6
0.4
0.2
Δ Absorbance
0
80
0
80
0
Temperature in °C

FIG.8A


DNA linked Au colloids
Measured at 260 nm
Measured at 700 nm
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Δ Absorbance
0
80
0
80
0
80
0
80
0
Temperature in °C

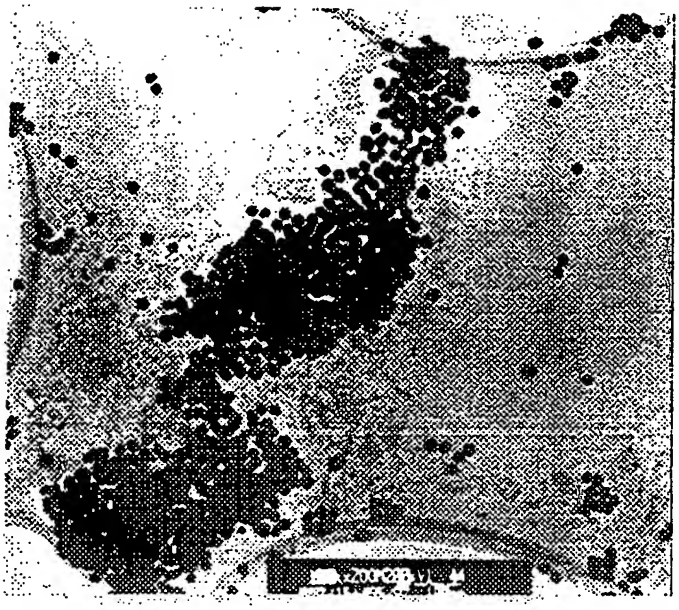


FIG.9A

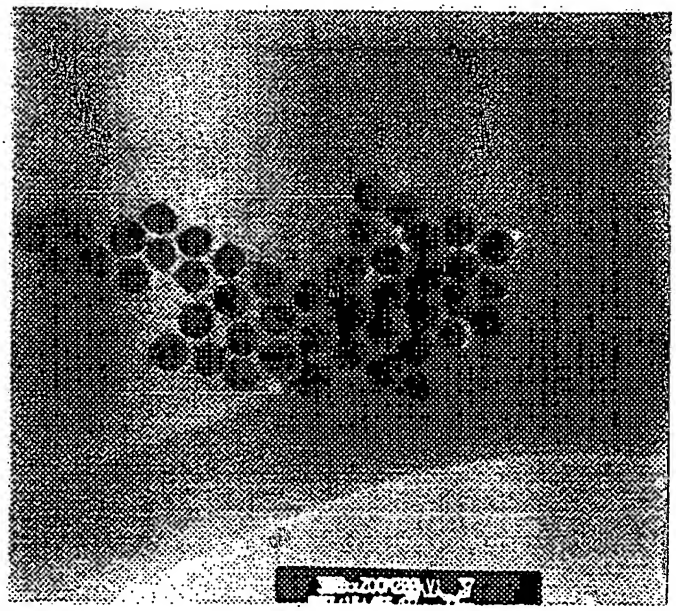


FIG.9B

FIG.10

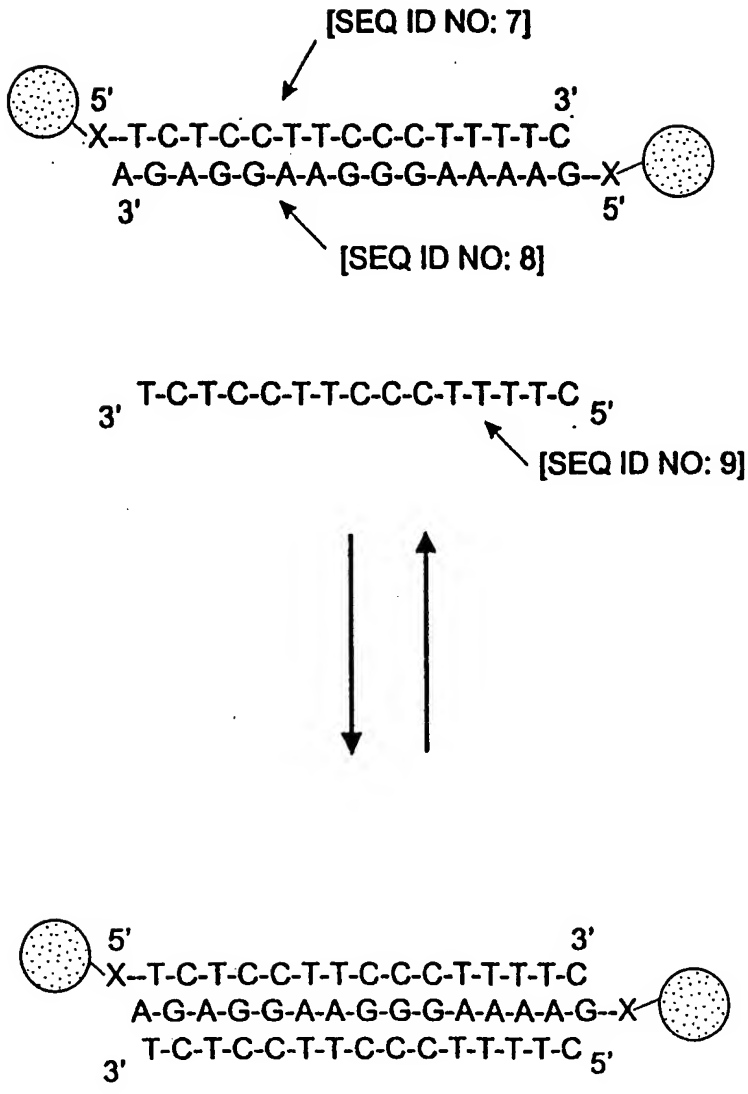

[SEQ ID NO: 7]
5'
3'
X--T-C-T-C-C-T-T-C-C-C-T-T-T-T-C
A-G-A-G-G-A-A-G-G-G-A-A-A-A-G--X
3'
5'
[SEQ ID NO: 8]
3'
T-C-T-C-C-T-T-C-C-C-T-T-T-T-C
5'
[SEQ ID NO: 9]
5'
3'
X--T-C-T-C-C-T-T-C-C-C-T-T-T-T-C
A-G-A-G-G-A-A-G-G-G-A-A-A-A-G--X
3'
T-C-T-C-C-T-T-C-C-C-T-T-T-T-C
5'

FIG. 11

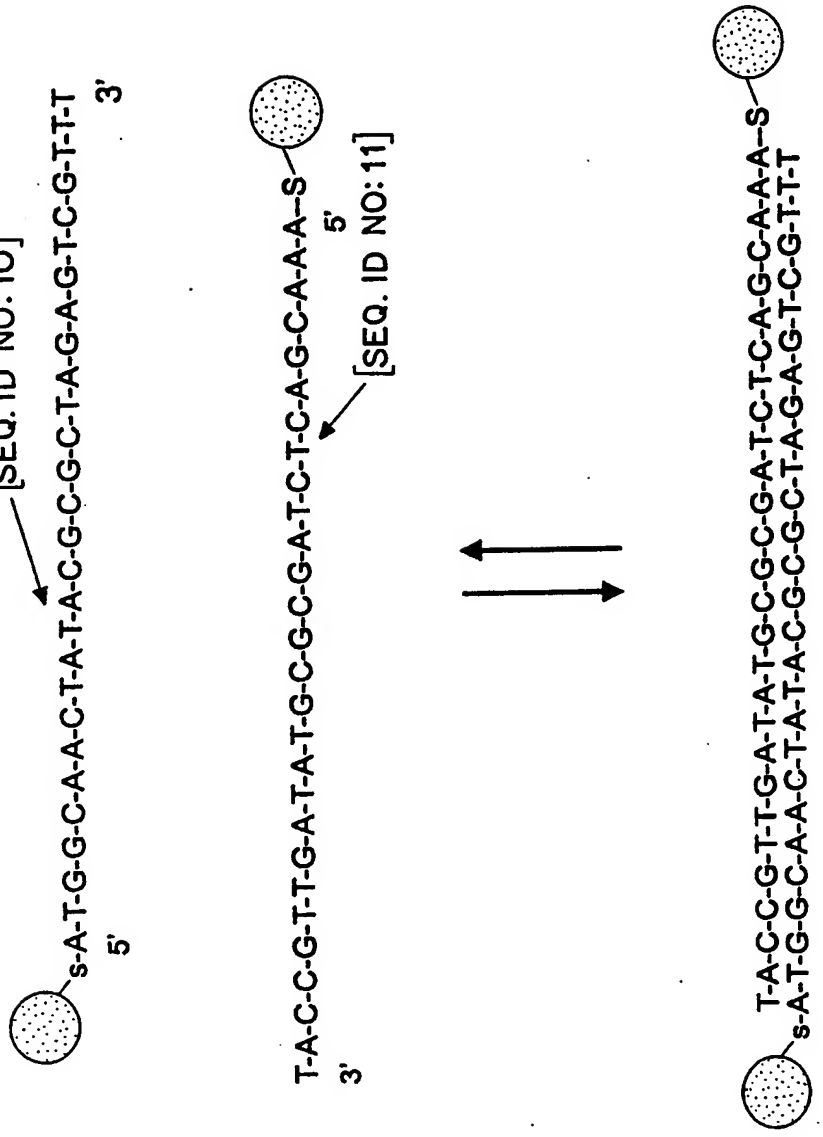

[SEQ. ID NO:10]
s-A-T-G-G-C-A-A-C-T-A-T-A-C-G-C-G-C-T-A-G-A-G-T-C-G-T-T-T
5'
3'
T-A-C-C-G-T-T-G-A-T-A-T-G-C-G-C-G-A-T-C-T-C-A-G-C-A-A-A--S
3'
5'
[SEQ. ID NO:11]
T-A-C-C-G-T-T-G-A-T-A-T-G-C-G-C-G-A-T-C-T-C-A-G-C-A-A-A--S
s-A-T-G-G-C-A-A-C-T-A-T-A-C-G-C-G-C-T-A-G-A-G-T-C-G-T-T-T

FIG.12A

Complementary Target

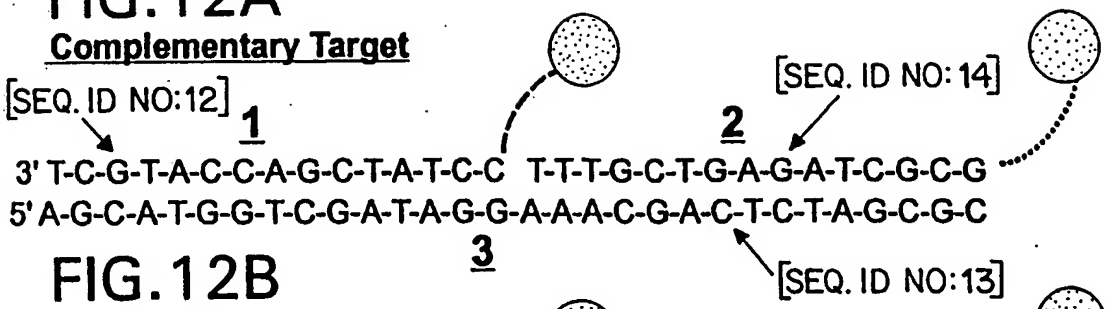


FIG.12B

Probes without Target

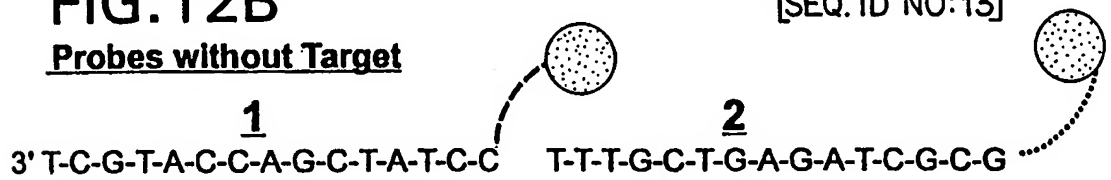


FIG.12C

Half Complementary Target

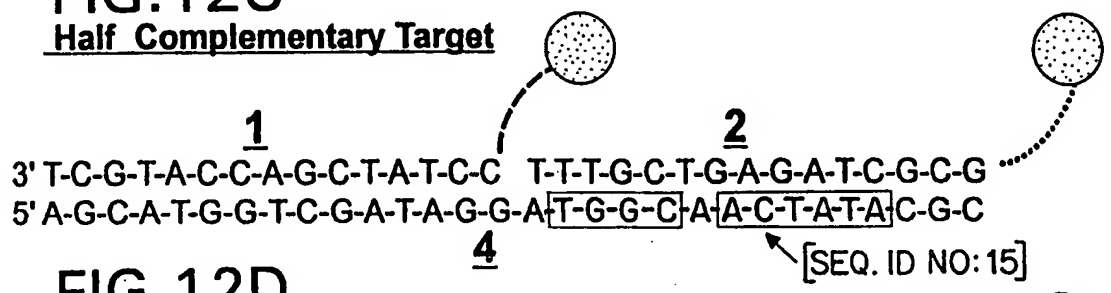


FIG.12D

Target - 6 bp

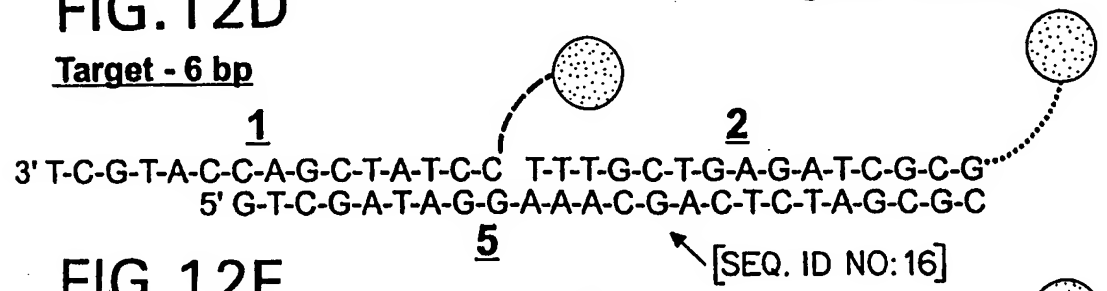


FIG.12E

One bp Mismatch

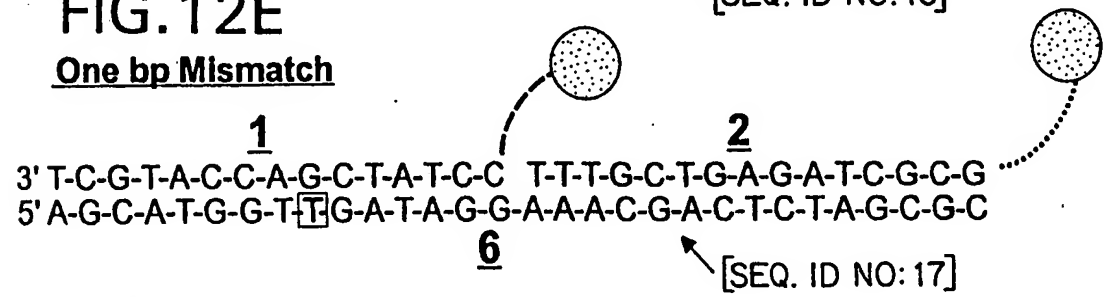


FIG.12F

Two bp Mismatch

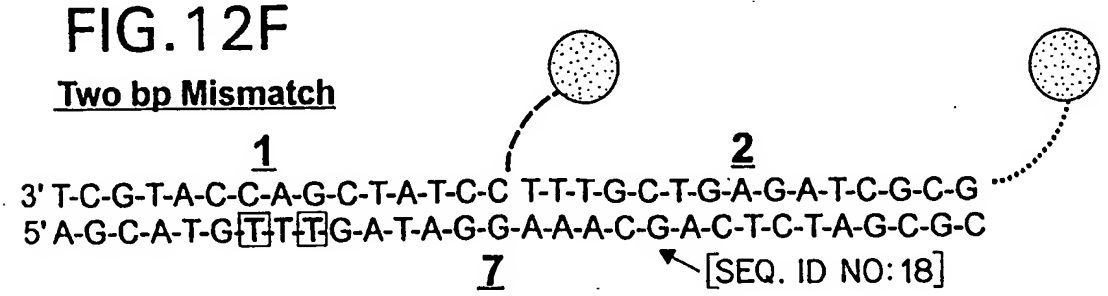
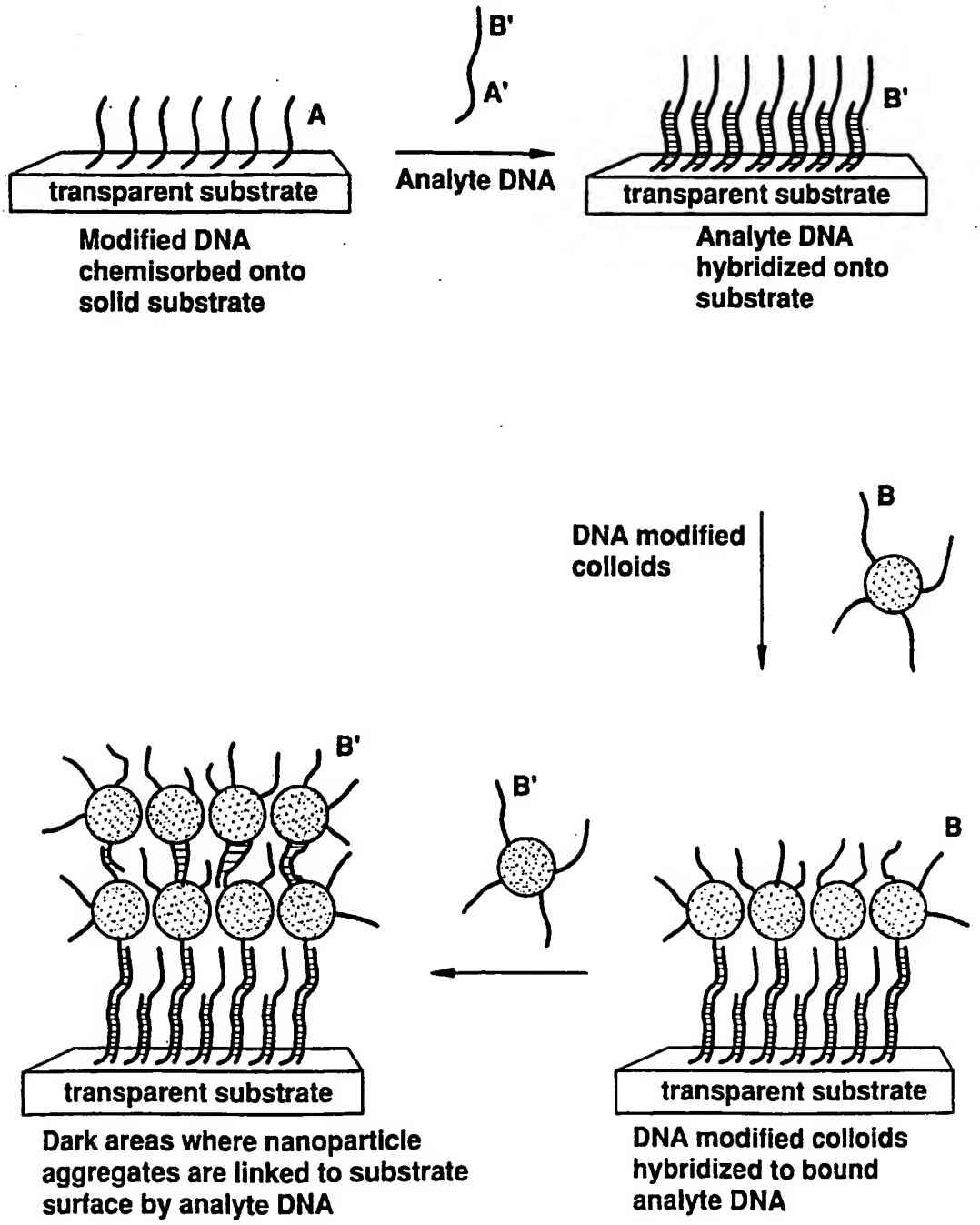


FIG.13A


B'
A'
A
transparent substrate
Analyte DNA
B'
transparent substrate
Modified DNA chemisorbed onto solid substrate
Analyte DNA hybridized onto substrate
DNA modified colloids
B
B'
B'
B
transparent substrate
transparent substrate
Dark areas where nanoparticle aggregates are linked to substrate surface by analyte DNA
DNA modified colloids hybridized to bound analyte DNA

14 / 22

FIG.13B

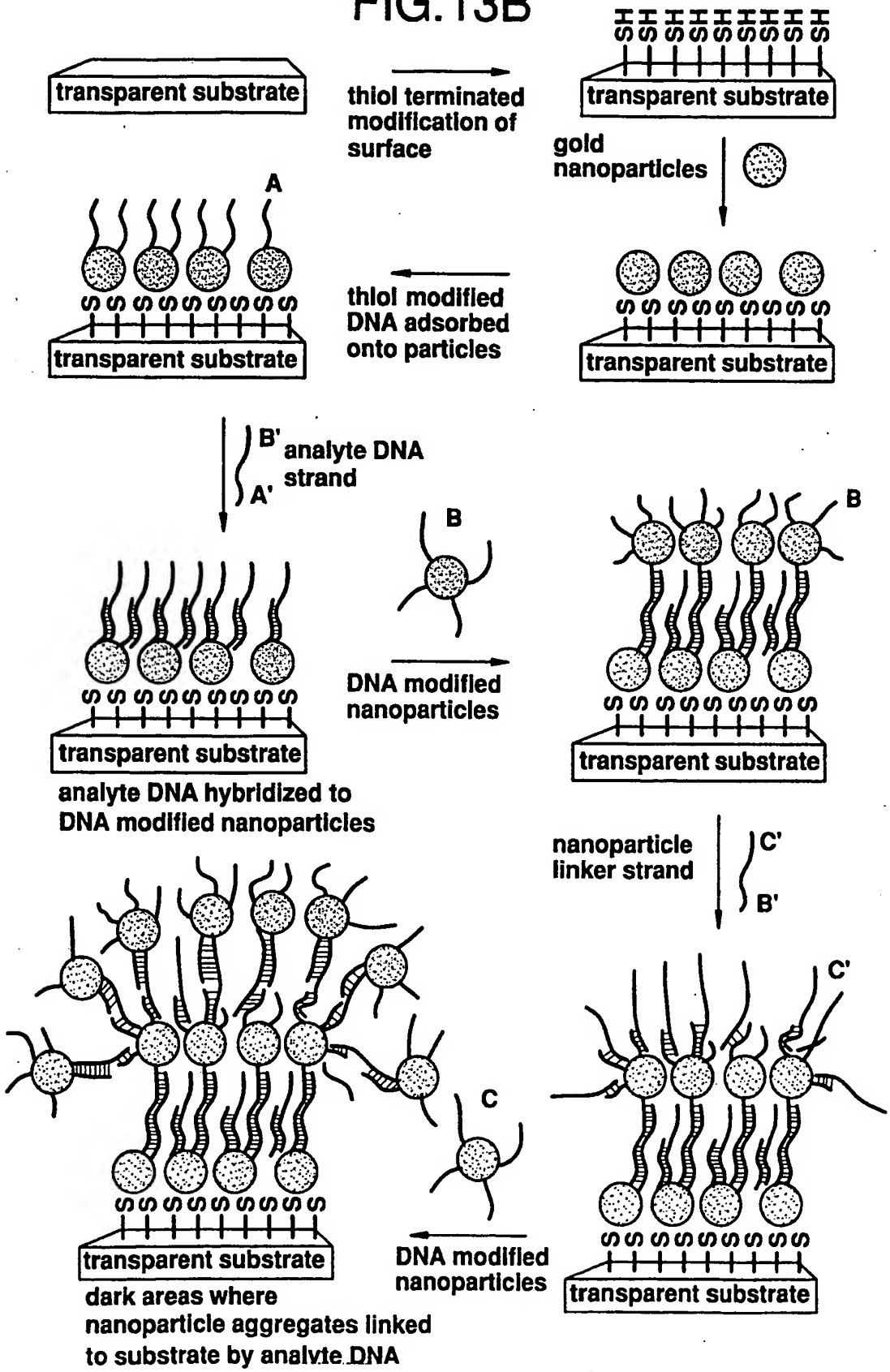

transparent substrate
thiol terminated modification of surface
transparent substrate
gold nanoparticles
A
thiol modified DNA adsorbed onto particles
transparent substrate
transparent substrate
B' analyte DNA strand
A'
B
DNA modified nanoparticles
B
transparent substrate
transparent substrate
analyte DNA hybridized to DNA modified nanoparticles
nanoparticle linker strand
C'
B'
C'
C
transparent substrate
DNA modified nanoparticles
transparent substrate
dark areas where nanoparticle aggregates linked to substrate by analyte DNA

FIG. 14A

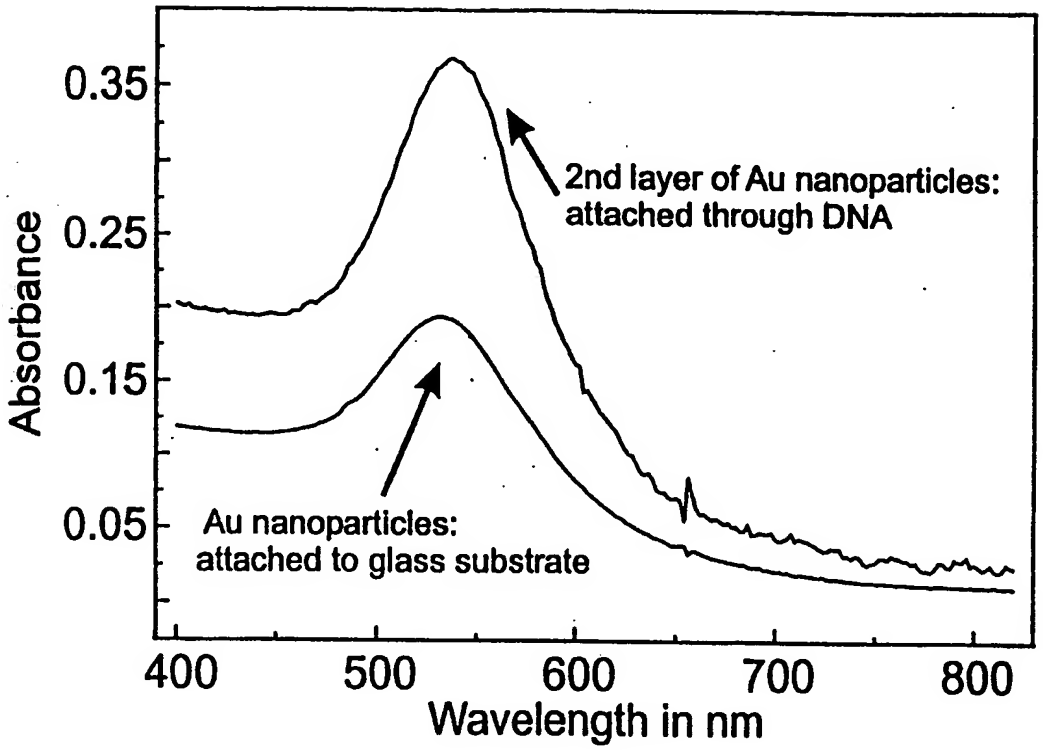


FIG. 14B

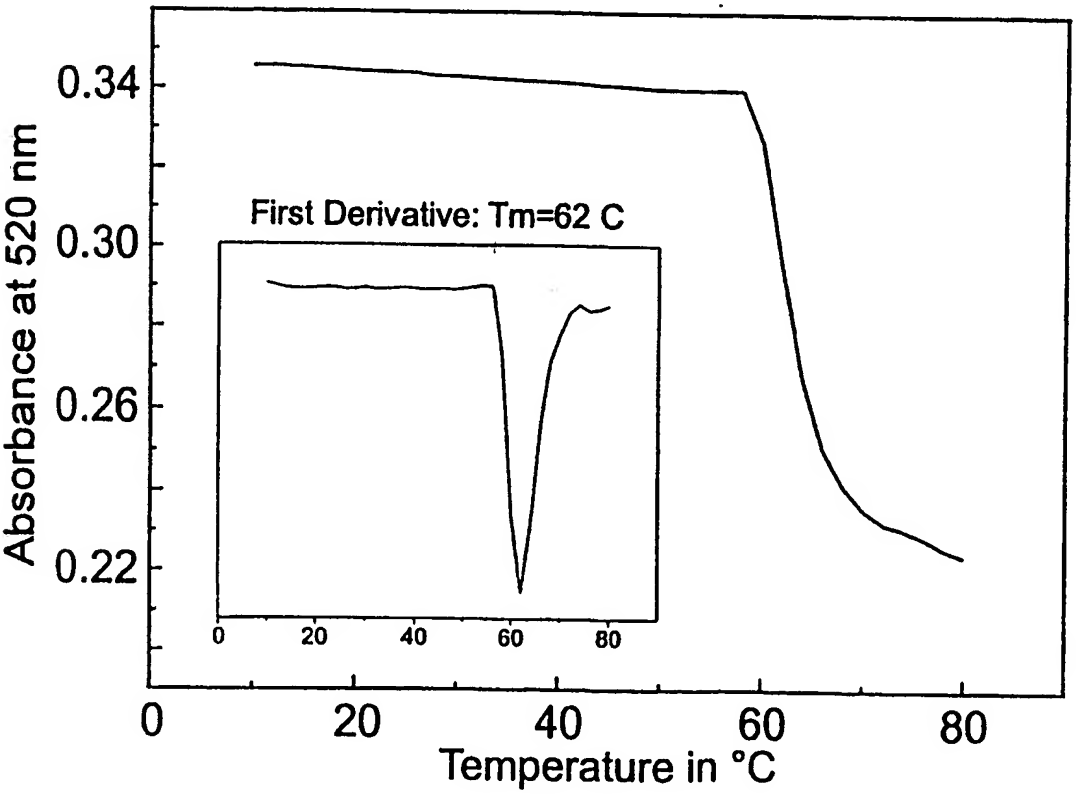


FIG15A

Probes with No Target

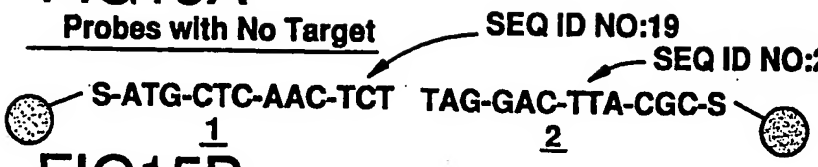


FIG15B

Half-Complementary Target

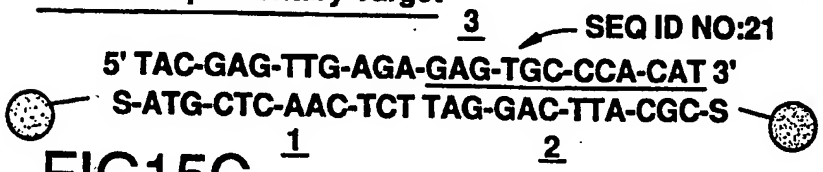


FIG15C

Complementary Target

Tm=53.5°C

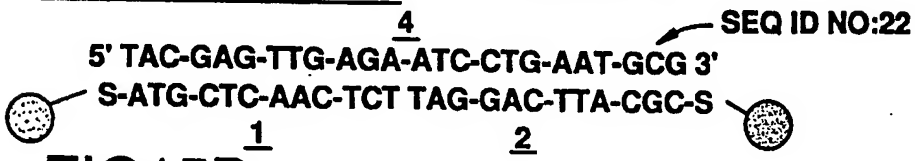


FIG15D

ONE Base-Pair Mismatch at Probe Head

Tm=50.4°C

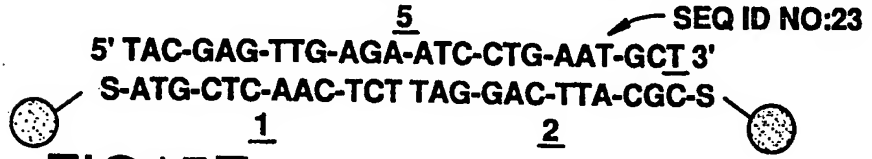


FIG15E

Tm=46.2°C

ONE Base-Pair Mismatch at Probe Tail

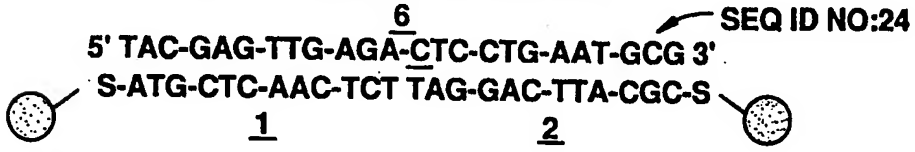


FIG15F

Tm=51.6°C

ONE Base Deletion

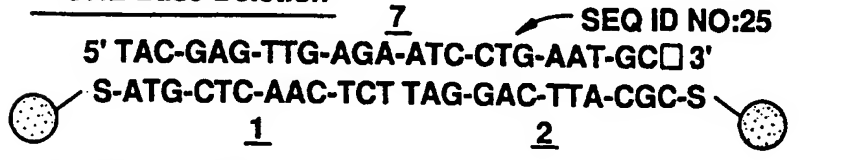


FIG15G

ONE Base-Pair Insertion

Tm=50.2°C

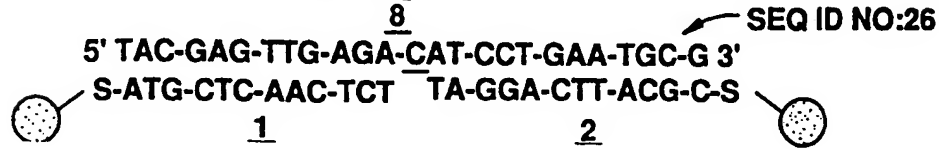


FIG.16A **24 Base Template**

5' TAC-GAG-TTG-AGA-ATC-CTG-AAT-GCG 3'
S-ATG-CTC-AAC-TCT TAG-GAC-TTA-CGC-S
1 2

FIG.16B **48 Base Template with Complementary 24 Base Filler**

5' TAC-GAG-TTG-AGA-CCG-TTA-AGA-CGA-GGC-AAT-CAT-GCA-ATC-CTG-AAT-GCG 3'
S-ATG-CTC-AAC-TCT GGC-AAT-TCT-GCT-CCG-TTA-GTA-CGT TAG-GAC-TTA-CGC-S
1 2

FIG.16C **72 Base Template with Complementary 48 Base Filler**

5' TAC-GAG-TTG-AGA-CCG-TTA-AGA-CGA-GGC-AAT-CAT-GCA-TAT-ATT-GGA-CGC-TTT-ACG-GAC-AAC-ATC-CTG-AAT-GCG 3'
S-ATG-CTC-AAC-TCT GGC-AAT-TCT-GCT-CCG-TTA-GTA-CGT-ATA-TAA-CCT-GCG-AAA-TGC-CTG-TTG TAG-GAC-TTA-CGC-S
1 2

FIG.17A

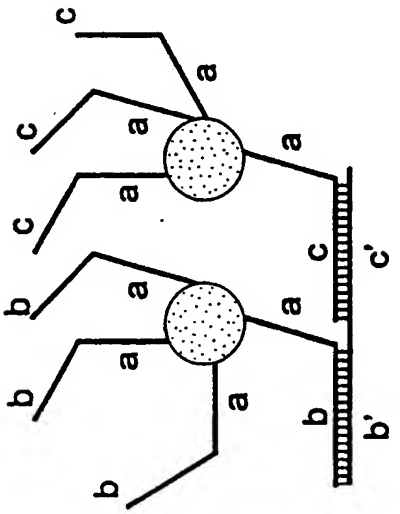


FIG.17B

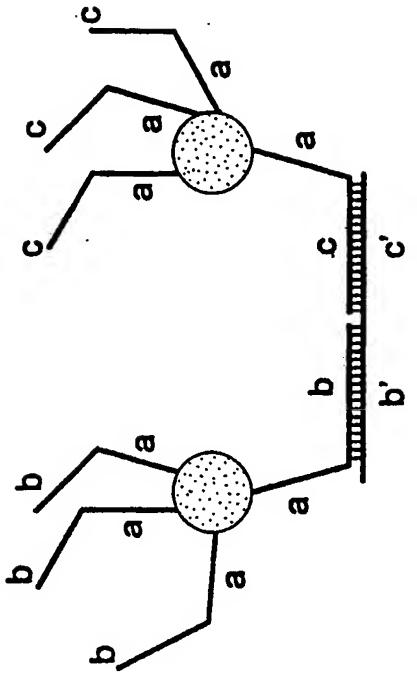


FIG.17C

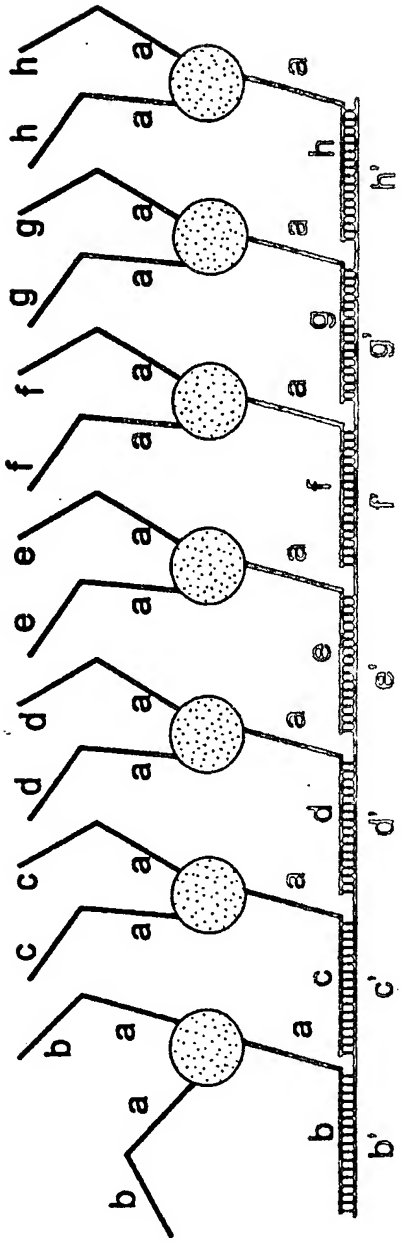


FIG.17D

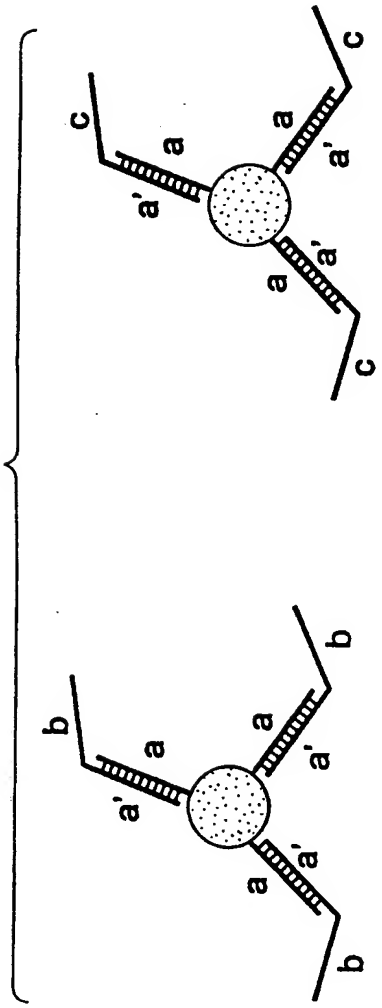


FIG.17E

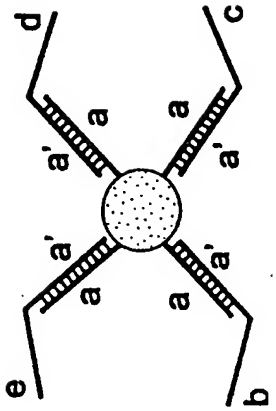


FIG.18

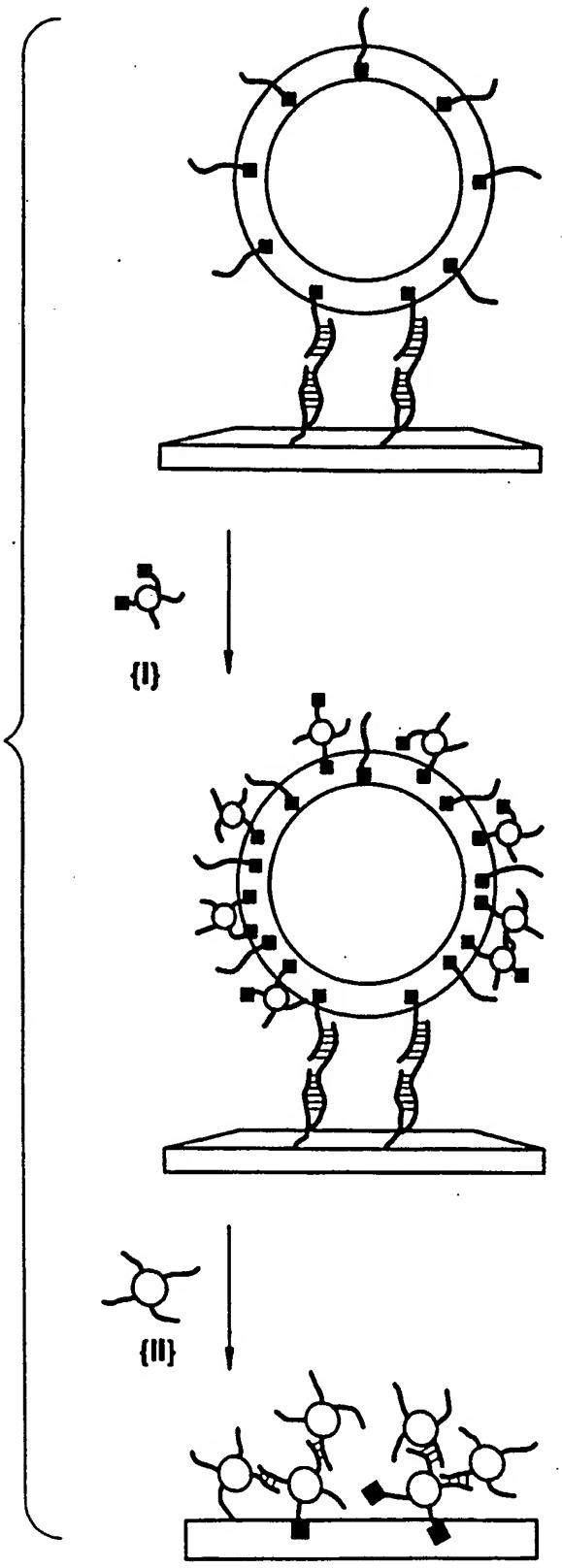


FIG. 19A

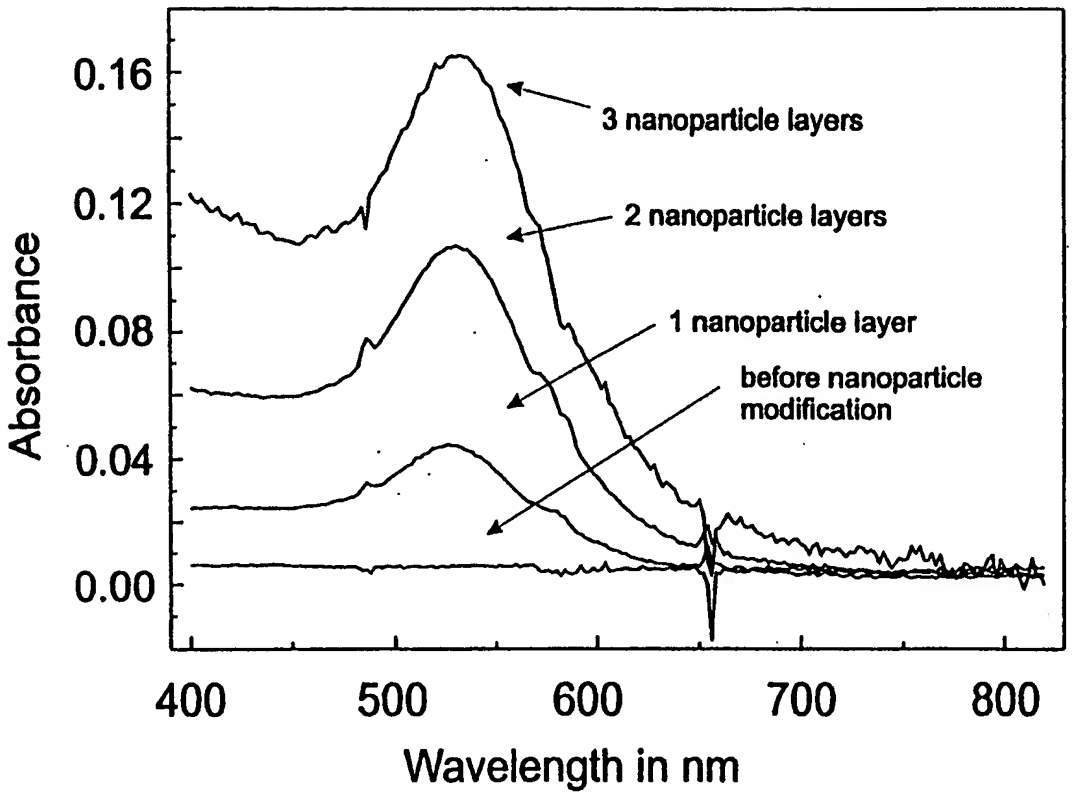


FIG. 19B

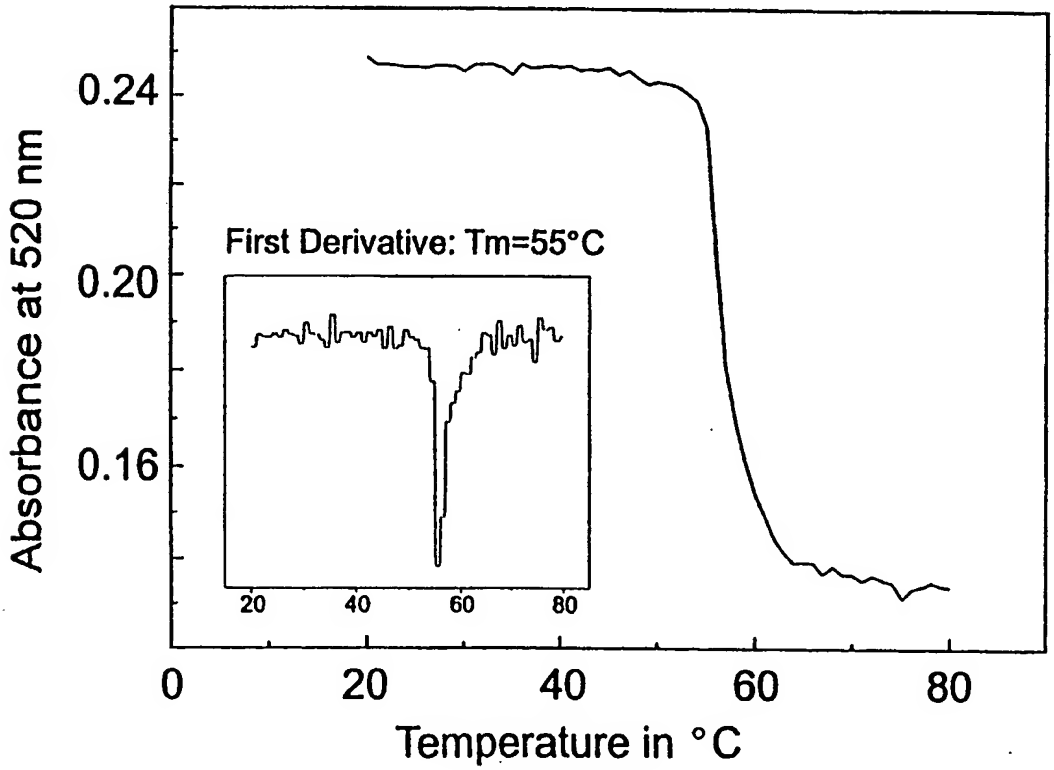


FIG.20A

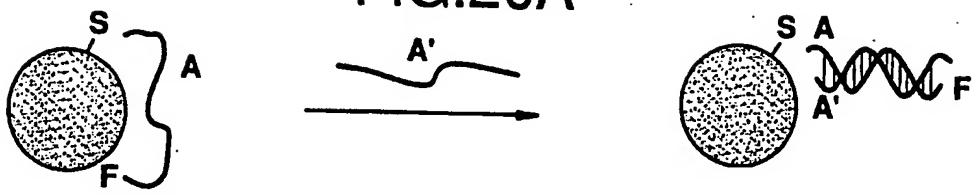
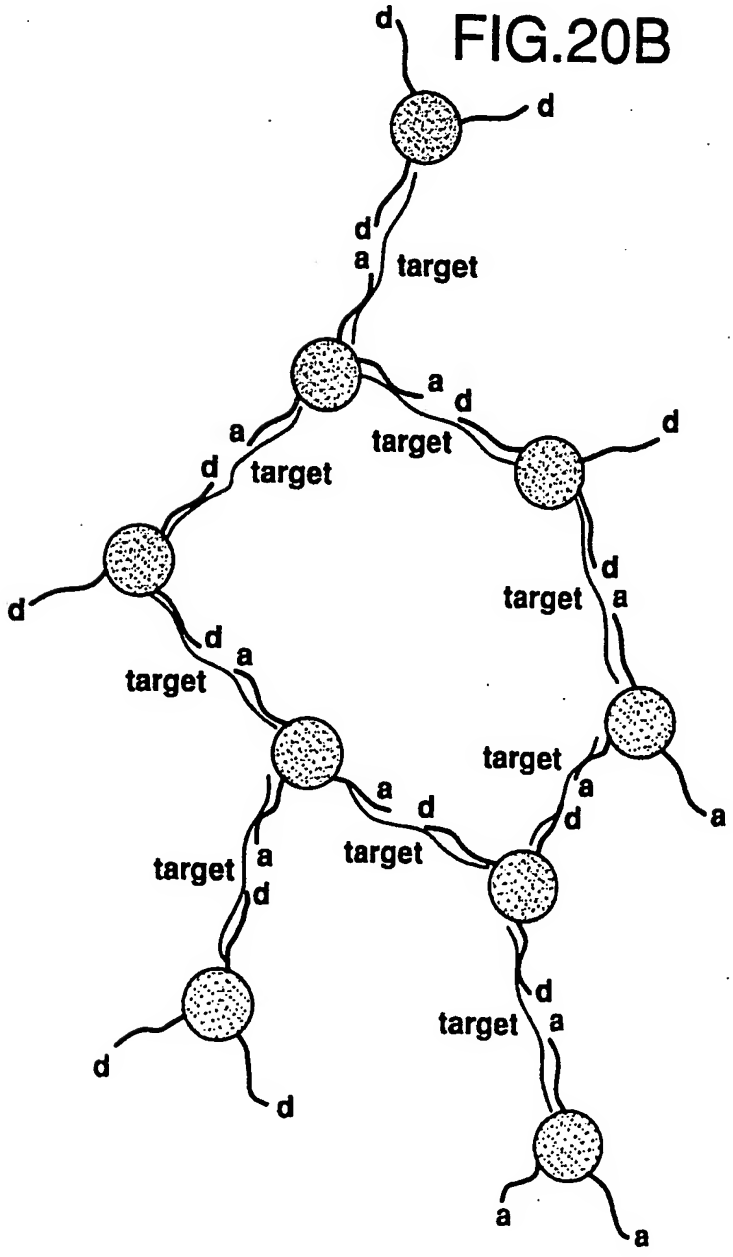


FIG.20B



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/12783

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) :C12Q 1/68; C12P 19/34; C07H 21/02, 21/04
US CL :435/6, 91.1; 536/23.1, 24.3, 24.32, 24.33
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
U.S. : 435/6, 91.1; 536/23.1, 24.3, 24.32, 24.33

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A, P	US 5,543,158 A (GREF et al.) 06 August 1996, see entire document.	1-88
A	US 5,460,831 A (KOSSOVSKY et al.) 24 October 1995, see abstract.	1-88
A, E	US 5,665,582 A (KAUSCH et al.) 09 September 1997, column 3, lines 7-10.	1-88

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search
19 SEPTEMBER 1997

Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/12783

B. FIELDS SEARCHED
Electronic data bases consulted (Name of data base and where practicable terms used):

APS, BIOSIS, BIOTECHABS, BIOBUSINESS,CABA, CASPLUS, EMBASE, CANCERLIT, AIDSLINE, JAPIO, MEDLINE, TOXLINE, TOXLIT, SCISEARCH, DISSABS, EUROPATFULL, EUROPEX, WPIDS, USPATFULL
search terms: nanoparticles, colloids or colloidal, oligonucleotides, polynucleotides, DNA, nucleic acids, hybridization, hybridisation, probes, primers, FET, energy transfer, donor acceptor, quenchers, quenching, gold, liposomes